The HOW AND WHY Wonder Book of

ENERGY AND POWER SOURCES

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THE HOW AND WHY WONDER BOOK OF

ENERGY AND POWER

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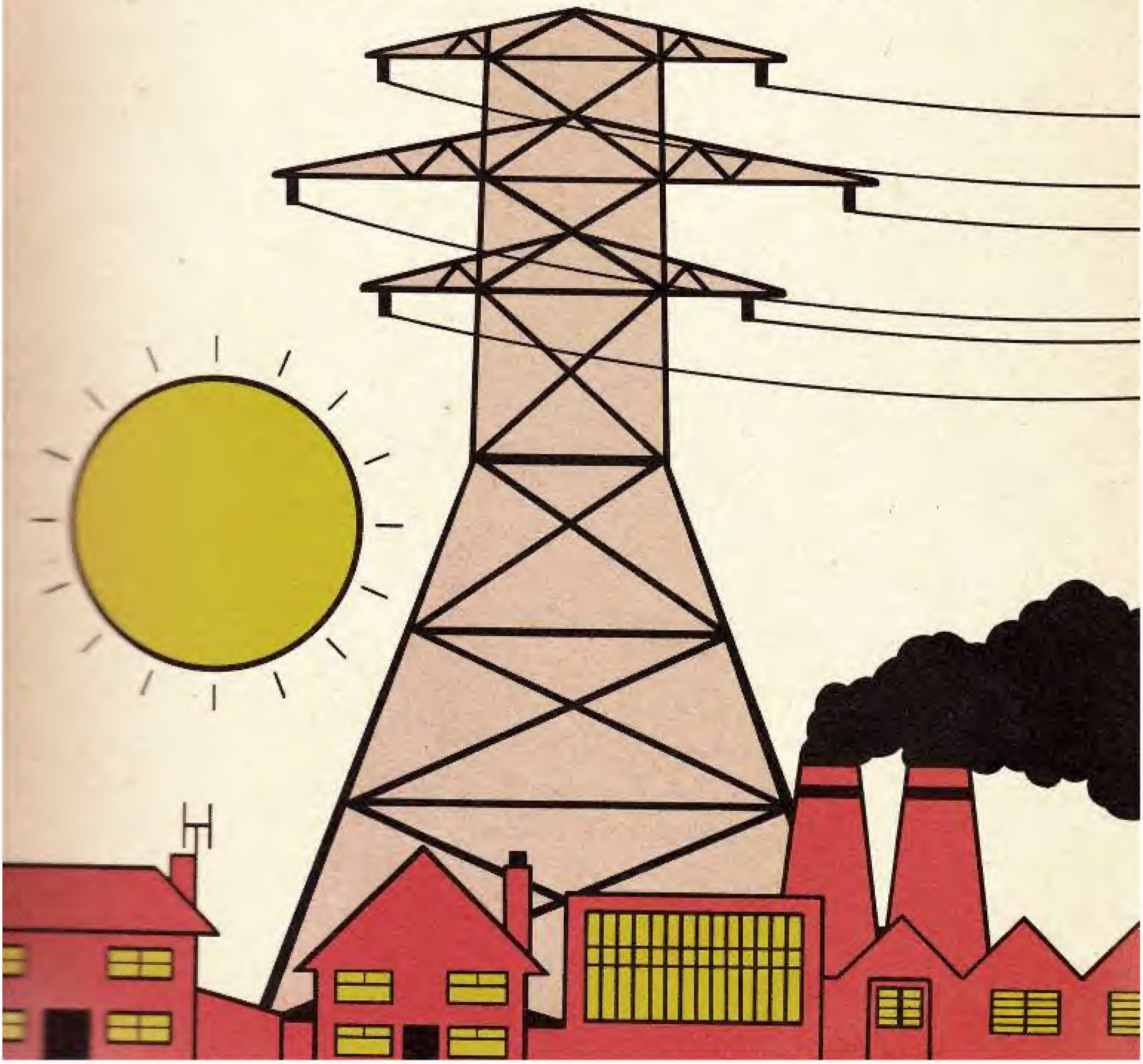

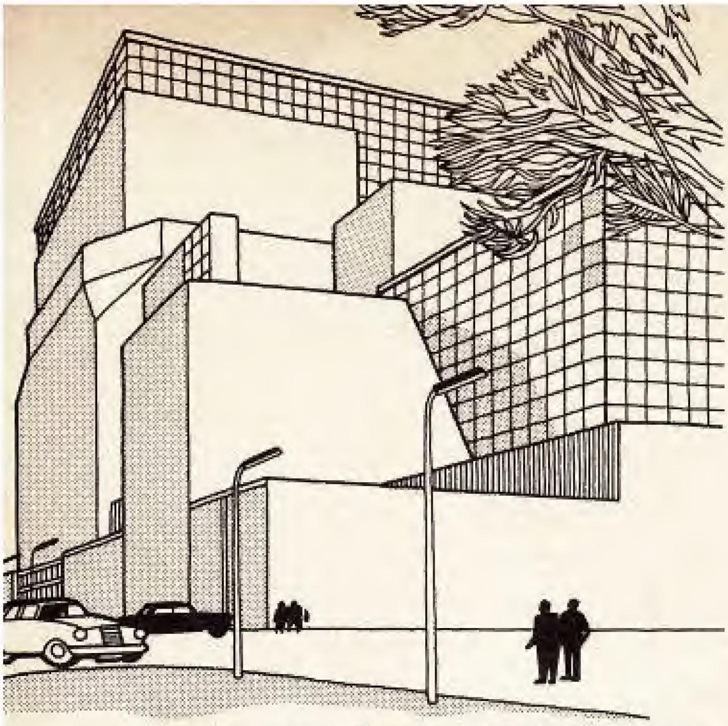

INTRODUCTION

Energy has always been (and always will be) the **cement** of modern civilised society. First, there were machines operated by the muscle-power of man or the toil of horse and oxen. The wheel, lever, pulley, inclined plane or ramp, and the windlass helped early man construct wondrous temples, palaces, and other structures which to this day startle our imagination and cause us to praise the engineering skill used by the ancients. Of course, we must not forget another 'energy' aid—the sail. Ships and boats rigged with sails took early civilised man across charted and uncharted seas, opening up new trade and increasing knowledge. The power of the wind was utilised on land too, windmills were coupled to heavy grinding stones used to mill corn. Water power was used for the same purpose.

Later, during the 18th and 19th centuries, man's curiosity took him into deeper and deeper regions of chemistry and physics. The new knowledge gained from these studies resulted in the industrial revolution. Coal and 'steam power' changed the outlook of mankind, practically every activity was touched by the invention of the steam engine. No longer was man dependent on the horse and ox, or on the whims of the wind—steam power meant railways and steam driven ships. The world grew smaller.

Coal gas also played a major role in the industrial society, lighting homes, offices, factories, hospitals, and streets. And the energy released by burning coal was used to heat the furnaces of industrial processes. Coal gas also 'cooked' food and warmed the home.

Then came the internal combustion engine, powered by 'petroleum', a new fuel extracted from wells of crude oil. By 1903, the first powered flight was made—propelled by a petrol-fuelled engine.

Meanwhile, electricity, once the curiosity and play-thing of 18th and 19th century scientists, had come of age. The energy of dammed water and that of steam was harnessed to drive electric-turbines, thus providing man with his second and possibly greatest industrial change. Electricity **is** the life-blood of the modern way of life.

By the mid-1930's, mankind was exploiting water power, coal, gas, electricity and petroleum at a rate that gave some experts cause for alarm. We were, they claimed, using up more and more energy and therefore depleting stocks of coal and oil that could not be replaced. But in those somewhat carefree times few took the warnings seriously.

The 1930's also saw the dawn of a new science—atomic physics (or nuclear physics as it is called today). Certainly this young science had its foundations back in the very early years of scientific investigation, but without electricity and the development of sophisticated instruments and atomic machines, very little progress had been made. Atoms are the basic building bricks of all matter—everything we know is built from these incredibly minute particles. By the outbreak of the Second World War it was clear that the atom was not only a fundamental piece of the universe—it was also the storehouse of considerable quantities of energy! The key to this energy lay with a process called 'nuclear fission' and the result was the atomic bomb! Today, we have perhaps learnt the error or our ways because atomic energy is serving man in a peaceful capacity; all over the world man is operating and constructing nuclear power stations which generate tremendous amounts of electricity from the fission of relatively small amounts of uranium.

But time has caught up with us and the warnings of an energy famine are part of our everyday life. Nobody chuckles and shakes their head when an expert warns that coal and petroleum will run out by 2025. Or that uranium, the precious fuel of nuclear reactors, will be depleted by 2050. Of course, we must not ignore this trend. Each day we learn of some new idea or scheme for generating electricity—the lifeblood of modern man. Some of these plans are discussed in this book but the reader must forgive me if no mention is made of erecting huge mirrors in Space in order to focus the heat of the sun towards collectors on earth. Or if I neglect the possibility of constructing vast floating cities which convert wave energy into electricity. These **are** exciting ideas but we have no way of achieving them in the time that is left. Instead, we must direct our attention towards **schemes that do work**—like using geothermal steam to generate electricity or harnessing fusion power—fuelled by the almost unlimited supplies of deuterium extracted from our oceans.

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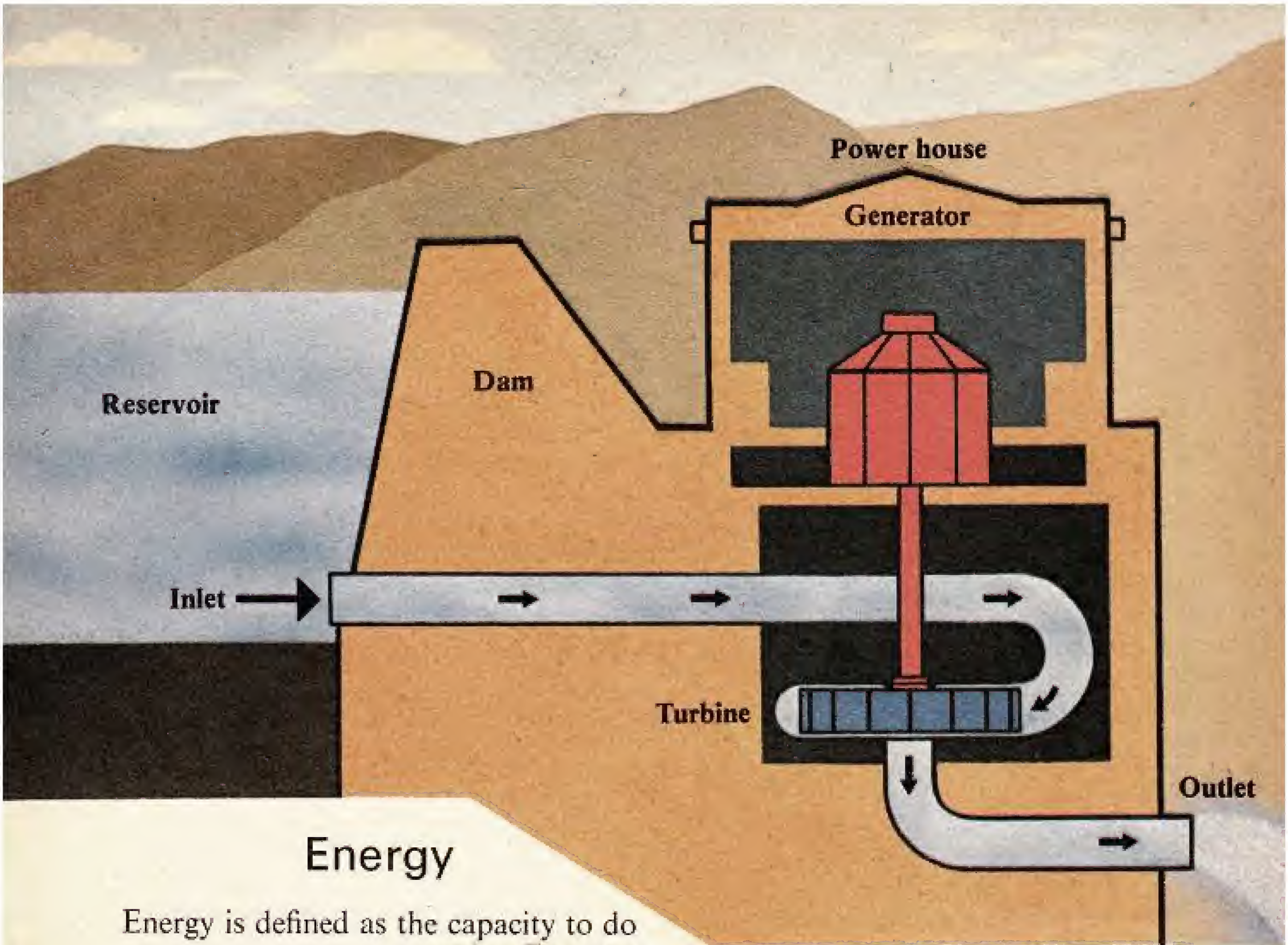


Energy

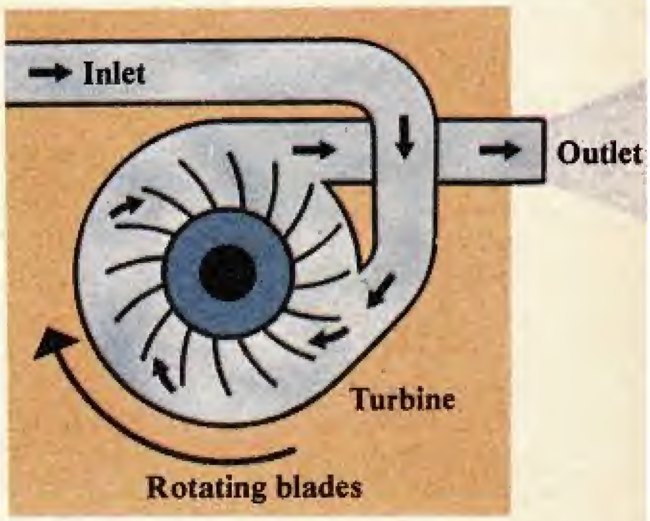
Energy is defined as the capacity to do work. Energy and work are measured in the same way by the same units.

Exactly what is energy?

Energy can be stored in a variety of forms:

(a) Mechanical Energy (Potential-Kinetic)
(b) Chemical Energy
(c) Heat (Thermal) Energy
(d) Electrical Energy
(e) Atomic Energy

When a huge amount of water is stored up behind the walls of a dam, it possesses *potential* energy. It has the potential to perform useful work. When the water is allowed to escape through pipes, it falls under the influence of the force we call *gravity* and performs a task of work when directed against the blades of a hydro-electric turbine. We say this fast-moving flow of water possesses *kinetic* energy, i.e. energy in motion. In this instance we are using the kinetic energy of the water to rotate mechanical machinery that produces electrical energy.



A HYDROELECTRIC POWER STATION. The 'potential' energy stored in dam water is released through pipe jets located at the base of the dam. Here, the 'kinetic' energy of moving water drives water turbines which in turn rotate the coils of electric generators—producing vast quantities of electricity.

The kinetic energy of streams and rivers is used by *water-wheels*. The *windmill* utilises the kinetic energy of the wind. In recent years it has been suggested that these two age-old machines could be coupled to electric generators to provide electric power for small communities.

A windmill and water-wheel—capturing the 'kinetic' energy of the wind and rivers.

When we speak of *chemical* energy we are referring to the kinetic energy that is locked inside chemicals and fuels that can be released in the form of mechanical, thermal, and electrical energy. For example, coal contains a combustible gas (i.e. it burns easily). Burning coal-gas consists of trillions of molecules doing a kinetic war dance; they are moving around very fast indeed. They warm up the air molecules by colliding with them and do the same to the molecules inside the metal of a saucepan of water. Then the molecules of water start to bounce around too and the water begins to boil. Some of the water molecules get so agitated that they leave the water and become a vapour called steam. Steam, trapped inside a boiler, is potential energy. When released, it works by driving the pistons (mechanical work) of a steam engine.

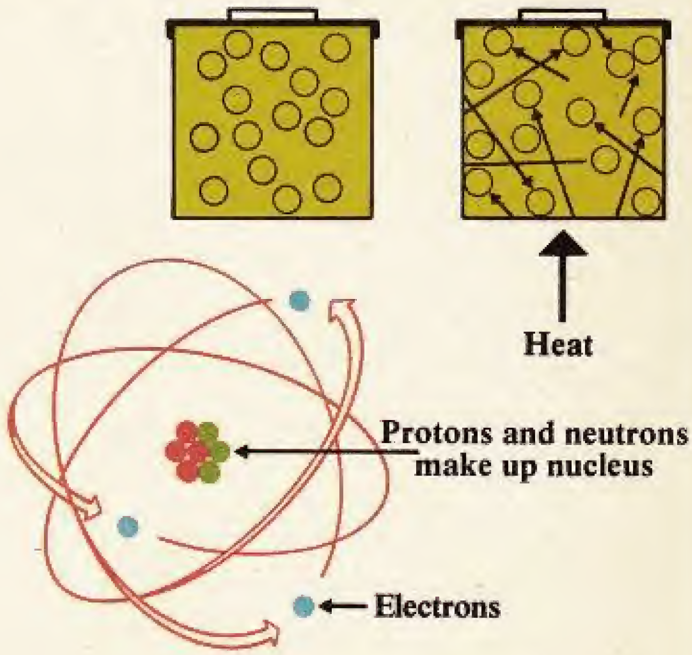
As we go further, we shall learn more of the nature of energy.

MATTER = ENERGY = MATTER

Everything that exists in the universe is made of stuff we call *matter*. Just as 'money' is the generalised name we give to all the coins that exist in our world, so the word matter is used to describe all the different things that exist in the universe. Matter is composed of millions of tiny particles called *molecules*.

Molecules are composed of still smaller particles called *atoms*. Atoms

An atom's structure and molecular motion with applied heat.



are made up of even tinier particles called *protons*, *neutrons* and *electrons*.

Until 1905, matter and energy were considered as being quite separate things. Then along came one of the world's greatest minds, Albert Einstein. Einstein's theories, backed by experimental evidence available at the time (and subsequently) plus highly involved mathematics, showed quite conclusively that matter = energy and energy = matter!

This theory made use of the speed at which light travels through a vacuum (space), namely 186,000 miles per second or 300×10^6 metres per second. This speed is considered the maximum speed at which anything can travel. Einstein said that if you accelerate a piece of solid matter towards the speed of light, it will change into pure energy. Conversely, if we knew how, matter could be produced from pure energy by slowing it down. This pure energy is mainly in the form of *electro-magnetic waves*. (See p. 16.)

Einstein's formula states: $E = Mc^2$ Where E = energy produced, M = mass (weight per given volume) and c^2 is the speed of light multiplied by itself.

The conservation of matter and energy

To *conserve* means to save or preserve intact. Therefore the conservation of matter and energy means to keep them intact. It has been understood since the 18th century that matter could not be destroyed, only changed in its form. Whereas the idea that energy cannot be destroyed was not established properly until the work of Einstein and others had proved the inter-relationship between energy and matter. Now, in the light of modern scientific evidence, it is an accepted fact that energy cannot be destroyed or created, but just transformed from one form to another.

TABLE OF

Atomic Number	Element	Symbol	Number of Protons and Electrons	Number of Neutrons	Atomic Weight
1	hydrogen	H	1	0	1·0
2	helium	He	2	2	4·0
3	lithium	Li	3	4	6·9
4	beryllium	Be	4	5	9·0
5	boron	B	5	6	10·8
6	carbon	C	6	6	12·0
7	nitrogen	N	7	7	14·0
8	oxygen	O	8	8	16·0
9	fluorine	F	9	10	19·0
10	neon	Ne	10	10	20·2
11	sodium	Na	11	12	23·0
12	magnesium	Mg	12	12	24·3
13	aluminium	Al	13	14	27·0
14	silicon	Si	14	14	28·1
15	phosphorus	P	15	16	31·0
16	sulphur	S	16	16	32·1
17	chlorine	Cl	17	18	35.5
18	argon	A	18	22	39·9
19	potassium	K	19	20	39.1
20	calcium	Ca	20	20	40·1
21	scandium	Sc	21	24	45·0
22	titanium	Ti	22	26	47·9
23	vanadium	V	23	28	50·9
24	chromium	Cr	24	28	52·0
25	manganese	Mn	25	30	54·9
26	iron	Fe	26	30	55·8
27	cobalt	Co	27	32	58·9
28	nickel	Ni	28	30	58·7
29	copper	Cu	29	34	63·5
30	zinc	Zn	30	34	65·4
31	gallium	Ga	31	38	69·7
32	germanium	Ge	32	42	72·6
33	arsenic	As	33	42	74·9
34	selenium	Se	34	46	79·0
35	bromine	Br	35	44	79·9
36	krypton	Kr	36	48	83·8
37	rubidium	Rb	37	48	85·5
38	strontium	Sr	38	50	87·6
39	yttrium	Y	39	50	88·9
40	zirconium	Zr	40	50	91·2
41	niobium	Nb	41	52	92·9
42	molybdenum	Mo	42	56	95·9
43	technetium	Tc	43	56	99·0
44	ruthenium	Ru	44	58	101·1
45	rhodium	Rh	45	58	102·9
46	palladium	Pd	46	60	106·4
47	silver	Ag	47	60	107·9
48	cadmium	Cd	48	66	112·4
49	indium	In	49	66	114·8
50	tin	Sn	50	70	118·7
51	antimony	Sb	51	70	121·8
52	tellurium	Te	52	78	127·6

ELEMENTS

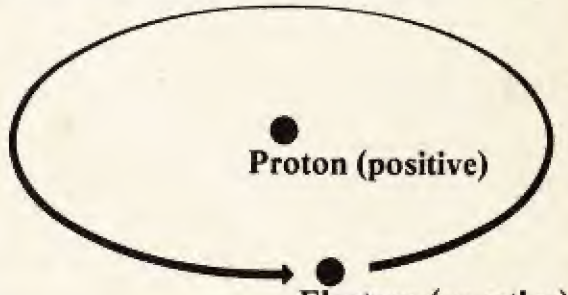
Atomic Number	Element	Symbol	Number of Protons and Electrons	Number of Neutrons	Atomic Weight
53	iodine	I	53	74	126·9
54	xenon	Xe	54	78	131·3
55	caesium	Cs	55	78	132·9
56	barium	Ba	56	82	137·3
57	lanthanum	La	57	82	138·9
58	cerium	Ce	58	82	140·1
59	praseodymium	Pr	59	82	140·9
60	neodymium	Nd	60	82	144·2
61	promethium	Pm	61	86	147·0
62	samarium	Sm	62	90	150·4
63	europium	Eu	63	90	152·0
64	gadolinium	Gd	64	94	157·3
65	terbium	Tb	65	94	158·9
66	dysprosium	Dy	66	98	162·5
67	holmium	Ho	67	98	164·9
68	erbium	Er	68	98	167·3
69	thulium	Tm	69	100	168·9
70	ytterbium	Yb	70	104	173·0
71	lutetium	Lu	71	104	175·0
72	hafnium	Hf	72	108	178·5
73	tantalum	Ta	73	108	180·9
74	tungsten	W	74	110	183·9
75	rhenium	Re	75	112	186·2
76	osmium	Os	76	116	190·2
77	iridium	Ir	77	116	192·2
78	platinum	Pt	78	117	195·1
79	gold	Au	79	118	197·0
80	mercury	Hg	80	122	200·6
81	thallium	Tl	81	124	204·4
82	lead	Pb	82	126	207·2
83	bismuth	Bi	83	126	209·0
84	polonium	Po	84	125	209·0
85	astatine	At	85	125	210·0
86	radon	Rn	86	136	222·0
87	francium	Fr	87	136	223·0
88	radium	Ra	88	138	226·0
89	actinium	Ac	89	138	227·0
90	thorium	Th	90	142	232·0
91	protactinium	Pa	91	140	231·0
92	uranium	U	92	146	238·0
93	neptunium	Np	93	144	237·0
94	plutonium	Pu	94	150	244·0
95	americium	Am	95	148	243·0
96	curium	Cm	96	151	247·0
97	berkelium	Bk	97	152	249·0
98	californium	Cf	98	151	249·0
99	einsteinium	Es	99	155	254·0
100	fermium	Fm	100	153	253·0
101	mendelevium	Md	101	155	256·0
102	nobelium	No	102	152	254·0
103	lawrencium	Lw	103	154	257·0

Elements of Atoms

Elements of atoms

All chemical substances that go to make up our products, our world and the universe, are built from 92 basic *elements* of matter. The Table seen here, lists all of these elements and also shows the additional 11 elements produced artificially in nuclear machines. Since there are only 92 basic elements, there are only 92 basic *atoms*.

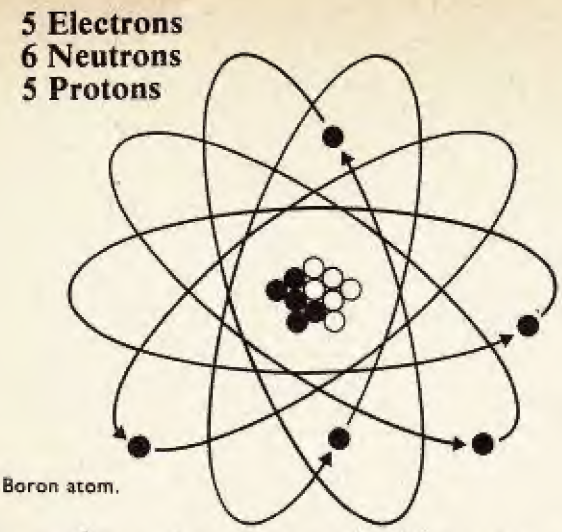
An atom is an extremely small particle, so small in fact that not even the most powerful electron microscope can pick one out individually. The central core of an atom is called the *nucleus* (*nuclei* if more than one is being discussed). The nucleus contains one or more particles called *protons*. Protons are *positive* charges of electricity.



Hydrogen—the simplest atom.

With the exception of hydrogen atoms, all the remaining elemental atoms also have neutral charges at the nucleus in the form of particles called *neutrons*. Up to about Calcium in the Table, the balance between protons and neutrons is about the same, but after this, the ratio of neutrons to protons noticeably increases.

ALWAYS remember: the number of protons in a given atom signifies which element it is. This number is in fact called the *atomic number*. For example, an atom with an atomic number of 5 would belong to the element *Boron* and have 5 protons in



A Boron atom.

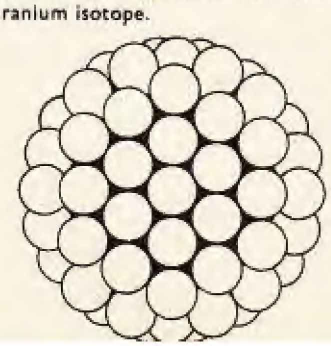
its nucleus. An atom with 34 protons and therefore an atomic number of 34, is the element *Selenium*. So it goes on. Both protons and neutrons weigh about the same and have similar diameters. Because atoms are so small, their weight is measured by counting the total number of protons and neutrons there are in the nucleus.

This is called the *atomic weight* of an atom. Thus an atom having 12 protons and 12 neutrons will have an atomic weight of 24. This is an atom of Magnesium. Uranium has more than one atomic weight because it exists in several *isotopic forms* (see page 44), but for the purposes of this section we shall use the most abundant form of uranium which has an atomic weight of 238. This atom has 92 protons and 146 neutrons in its nucleus.

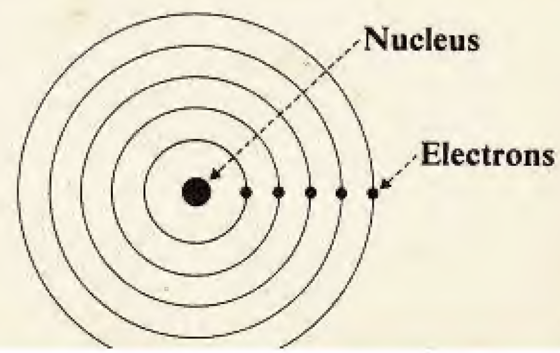
Last, but not least, in our examination of the atom, we come upon particles called *electrons*. If we could look into an atom of hydrogen, we would see just one solitary electron circling the solitary proton at the nucleus. If we were to examine the remaining elemental atoms we would discover that the number of electrons orbiting the nucleus exactly equals the number of protons residing there. Electrons are *negative* charges of electricity, approximately 2,000 times lighter in weight than a proton or neutron although they are larger. Atoms distribute their orbiting electrons into a series of layers (correctly called *shells*). If, at the end of arranging its electrons into these layers, the atom has less than 8 electrons in its outermost layer, the atom will try to combine with another atom or atoms to rectify this deficiency. This is a basic rule of chemistry and is the mechanism whereby elements combine to make the millions of different *chemical compounds* that exist. The bonding of atoms is extremely important in the study of fuels and energy, since the breaking of these bonds releases heat and light energy.

Special Note: Atoms consist of two kinds of charged particle. Since it was found that electrons repel each other when emitted by the negative electrode of a cathode ray tube (plus other processes) it was natural to give these particles a *negative* charge. On the other hand, protons repel each other but attract electrons. Hence these particles were given a *positive* charge. Neutrons possess neither negative nor positive charge and are thus regarded as being neutral.

The nucleus of any atom (except Hydrogen) consists of clusters of protons and neutrons. The nucleus illustrated below is a uranium isotope.



ELECTRON SHELLS. Atoms arrange orbiting electrons into shell-like layers. When electrons 'jump' into higher or lower shell layers they emit or absorb radiation. The electrons in the outermost shell are the links by which atoms join together to make the thousands of different substances which exist.



Mechanical Energy

The lever

Levers are one of man's earliest inventions. Though not as old as the flint and iron hammers of primitive man, they work on the same principle. Levers enable muscle power to be put to greater advantage. Given the right kind of lever, a man could move a bus. In its simplest form, a lever consists of a rigid bar or plank which moves across a fixed point called either a *pivot* or *fulcrum*. Three terms are used to describe the operation of levers. The weight to be moved is called the *load*. The muscular force applied to the lever is called the *effort*. The mathematical ratio between these two (they are measured in pounds or grams/kilograms) is called the *mechanical advantage*.

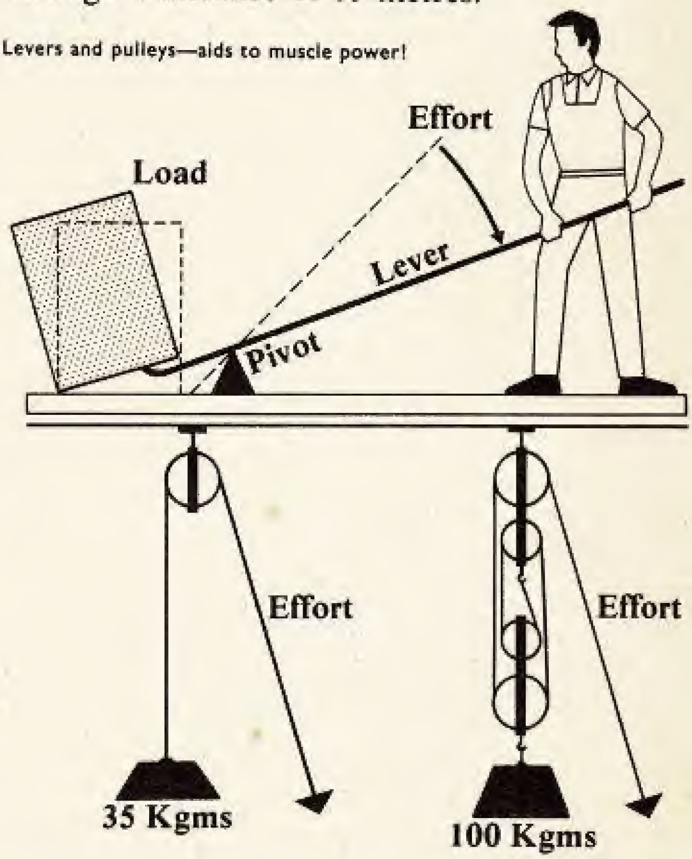
The simplest lever would be the familiar toy—a child's see-saw. If Jack and Jill were seated at opposite ends of their see-saw and Jack weighed more than Jill, Jill would be tipped up into the air! If Jill sat further from the pivot than Jack, her section of the plank would be longer, the leverage would be in her favour and Jack would be shot up into the air!

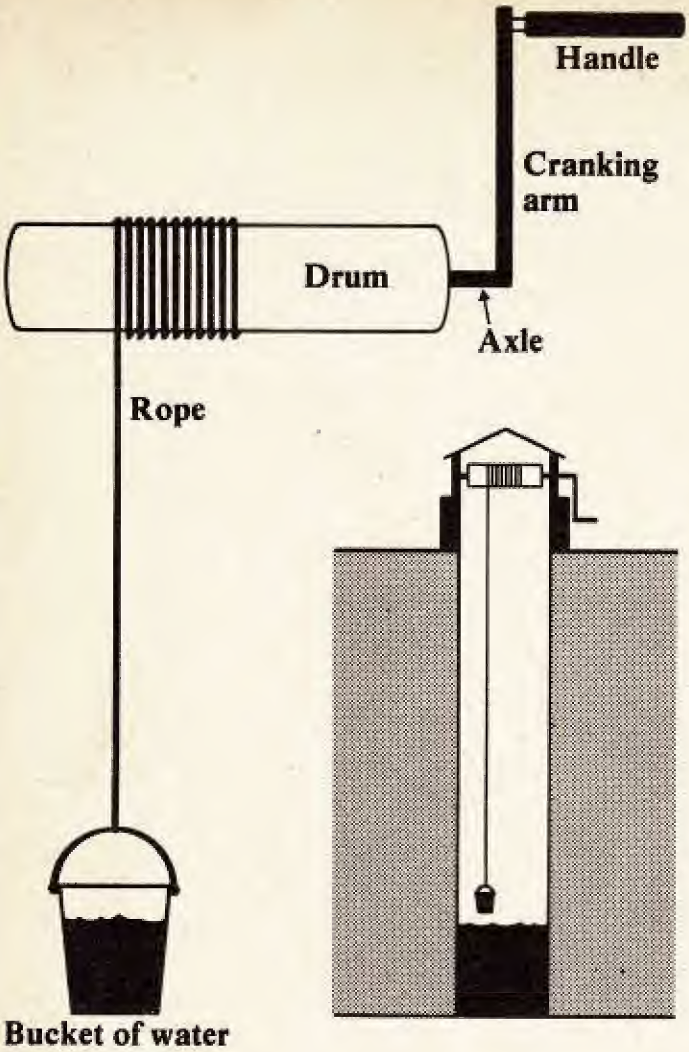
There are very many examples of levers in our everyday world: the claw-hammer, nut-crackers, boat oars, pliers, the human arm, the wheelbarrow and many more.

The pulley

Pulleys are basically modified levers. They also enable man to lift objects weighing far more than himself. Essentially, a pulley system consists of a rope or chain running over a rimmed wheel which is mounted into a metal or wooden block and supported by a rigid bar or beam. It is far easier to lift a load by pulling down on a rope than by stooping over it and attempting to lift it. Pulleys share the same terms as levers: pivot or fulcrum, load, effort and mechanical advantage. A *fixed pulley* is a simple pulley and can only provide a mechanical advantage of ONE. This means that to lift 35 Kgms. load, 35 Kgms. effort must be applied to the end of the rope. A *movable pulley*, commonly called a 'block and tackle', uses several pulleys in combination with each other. The mechanical advantage of this pulley system is FOUR. This means that the effort required to lift a load of 100 Kgms. is only 25 Kgms.! Quite an advantage! When using this form of pulley system it is important to realise that the load moves only a quarter of the distance that the effort moves. This means that for every metre of rope you pull down on, the load will only move ·25 mtrs. (25 cms.). So you will need a rope at least 60 metres long if you are lifting loads through a distance of 15 metres.

Levers and pulleys—aids to muscle power!





A windlass.

The windlass

A windlass is a very old mechanical machine. Its name probably originates from the old word *windle* meaning 'to wind'. A windlass consists of an axle and drum around which a rope or chain is wound when the axle is turned. At first this simple machine was used to lift heavy buckets of water from deep wells. Medieval castles also applied them in war machines and as a means of raising and lowering the drawbridge. Sailing ships also found the windlass useful in hauling sails and anchors. A windlass is most efficient when it has a thin diameter drum and a long cranking arm.

The *effort* to be exerted on the cranking arm to raise a specific *load* is calculated by the following simple formula:

$$\frac{\text{weight of bucket} \times \text{drum radius}}{\text{crank arm length}} = \text{effort required}$$

Thus a bucket of water weighing 30 lbs. (13·6 Kgms.), a drum radius of 6 inches (15·2 cms.) and a cranking arm of 24 inches (60·9 cms.) = a cranking effort of 7·5 lbs. (3·4 Kgms.). Each rotation of the cranking arm winds approximately 3 feet (91 cms.) of rope onto the drum, therefore we can easily work out how many turns of the arm are needed to bring this load up a 66 foot (20·1 metres) well shaft:

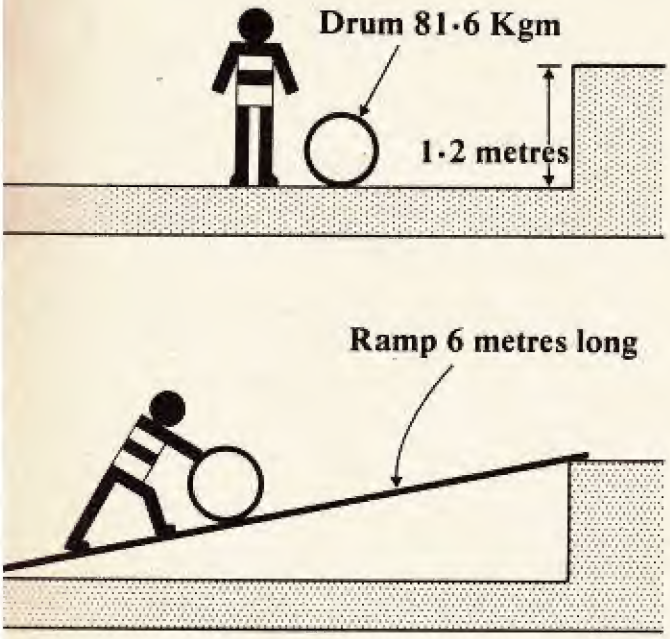
$$\frac{66 \text{ feet}}{3 \text{ feet}} = 22 \text{ turns or } \frac{20 \text{ metres}}{\cdot 9 \text{ metres}} = 22 \text{ turns}$$

When a load is moved through any distance we measure the amount of work done in units called *foot-pounds*. Metric calculations are not expressed in centimetre-grams or metre-kilograms, but are converted into work units called newton-metres, ergs, or joules. One newton-metre = 10,000,000 ergs = one joule = 0·73 foot-lbs.

The inclined plane

The ancient builders of temples and pyramids used inclined planes extensively to erect these huge monuments to religion and belief. Today we can see versions of the inclined plane everywhere we look, only nowadays these useful mechanical devices are called *ramps*. Ramps are used by the local restaurant or public house to roll barrels of beer and wine into their premises or empty barrels onto a truck. We can see ramps being used for similar purposes anywhere where loads are cylindrical, heavy. and only man-power is available.

Inclined planes serve to redistribute the total foot-pounds work involved in a particular task. For example: if a man wishes to raise a 180 lb. drum of



Inclined plane or ramp—another aid to muscle power!

oil off the ground to the floor of a warehouse that is 4 feet above ground level, the total work involved will be 4 ft. × 180 lbs. = 720 ft.-lbs. work.

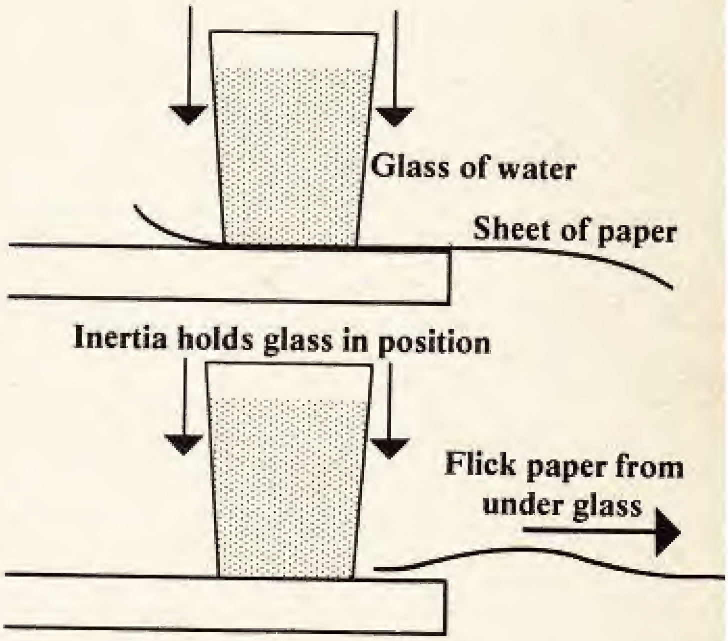
Now, no man (unless a weight-lifter) can produce this kind of effort without straining himself, especially if this effort is required more than once. But if the man uses a ramp of 20 feet he only needs to muster 36 lbs. of effort to roll the drum up the 'incline' to its resting place inside the warehouse. The 720 ft.-lbs. are divided by the 20-foot incline.

The force of inertia

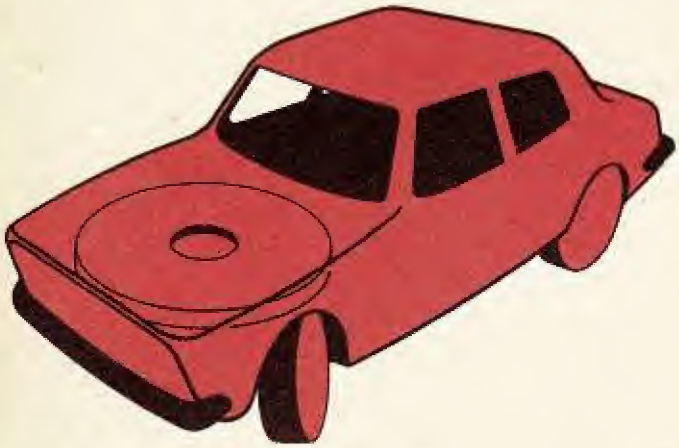
We would be very surprised to see a stone lift itself off the ground and fly through the air. Objects do not behave in this way. When they are still, they remain fixed in their positions. The ability of an object to maintain its position of rest is called *inertia*. The heavier, or more massive an object is, the greater is its inertia. However, if an object like a cannon ball is projected through the air at speed, its inertia will tend to keep it moving. Of course it will eventually fall to the ground as a consequence of another force called *gravity*.

Gravity is a force that exists throughout the entire universe. Like magnetism, it attracts objects. A large dense planet has more gravity than a smaller less dense planet. It is gravity that holds us to the surface of the earth and keeps the earth circling the sun.

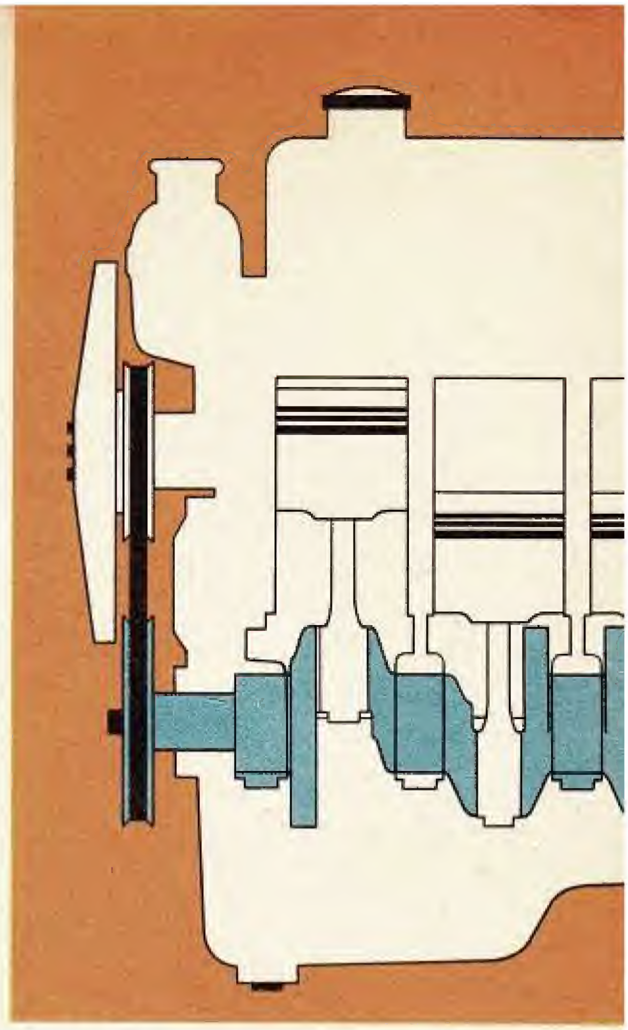
A simple demonstration of inertia.



Another interesting fact regarding inertia is that it tends to increase with the speed of an object. If you tie two balls to a piece of string, one ball at the end of the string and the other about a foot further in, then twirl them around your head, the outer ball will possess a greater amount of inertia. This is because it has to travel faster to cover a greater distance in the same time as the inner ball traverses its path.



A flywheel-powered car.



What is a flywheel?

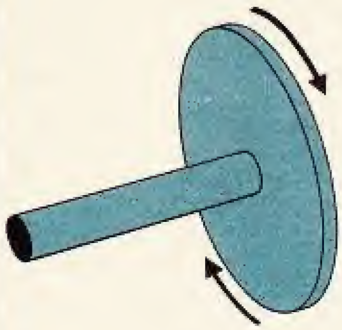
Flywheels make use of inertia. They are as old as civilisation itself and are mentioned in the Old Testament, as part of a potter's wheel. The inertia of a spinning-wheel tends to flatten out any irregularities in the power strokes of machinery to which they are coupled. Parts of machinery that move back and forth or rotate require the smooth influence of a flywheel or they will vibrate too much and damage the machine. In addition, the up and down and back and forth motion of pistons, wheels and drive rods requires to be as smooth as possible so that the machine delivers its power smoothly and regularly.

The early steam engine, for example, needed a stabilising influence because its parts were subject to a great deal of vibration and oscillation. The spinning drive-wheel required a smoothing force to prevent it from supplying irregular bursts of energy. The inertia of a heavy flywheel coupled to the drive-wheel succeeded in providing this stabilising effect. Today, all rotating machinery has the influence of a flywheel. Look inside a car engine, at a steam-roller, a record player motor and tape recorder motor, and inside your watch.

What are flywheel-driven vehicles?

Several years ago, Swiss transportation engineers designed, built and operated a bus that was powered solely by a large flywheel! The bus travelled from stop to stop, its wheels driven entirely by the mechanical energy stored inside a flywheel. Occasionally the driver of the vehicle pressed a button which operated machinery that coupled the flywheel up to an electric motor. The flywheel was run up to a high speed and then uncoupled from its energy source.

In America, engineers are designing and building very large flywheels in-



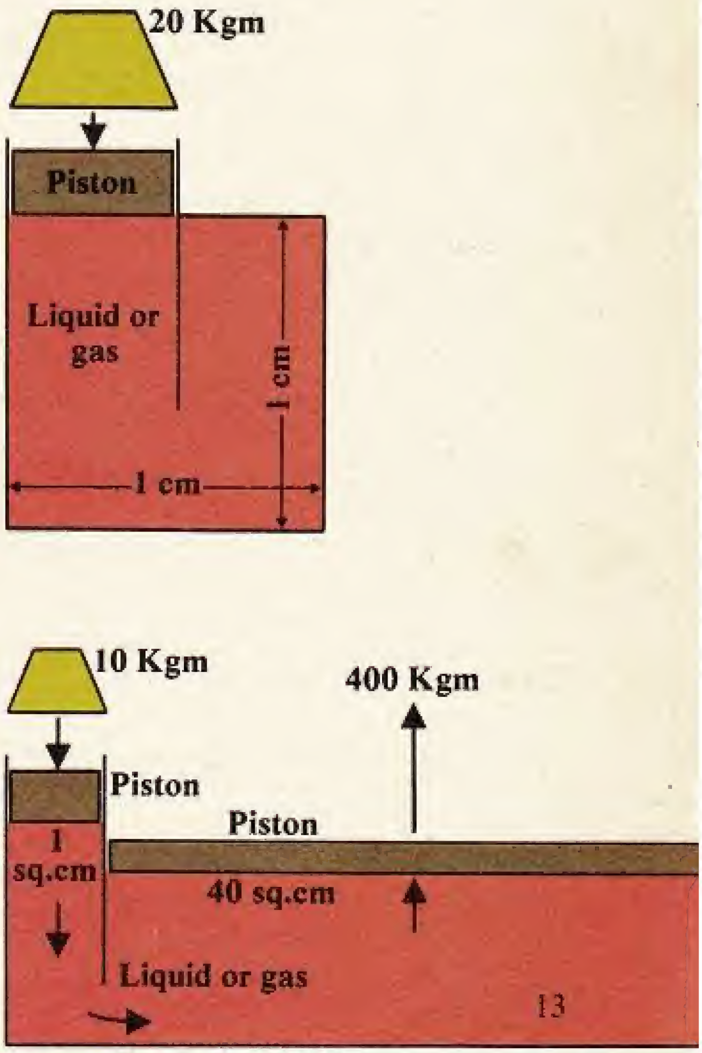
Motor vehicle engines use the 'inertia' of a revolving flywheel to smooth irregularities in power strokes.

deed. These will be used to store large amounts of mechanical energy and then, when necessary, be used to drive ordinary electric generators to provide electricity. Many new materials and flywheel shapes have been developed and several technical reports have been published about these research projects. One of the most interesting of these suggests the possibility of building a flywheel-powered automobile. With its flywheel encapsulated in a near vacuum to reduce friction and occasionally coupled to a small electric motor, this car looks very promising indeed. Think of it. No petrol to worry about—no pollution!

The principles of hydraulics

Liquids and gases have been found to be most useful in performing work. Many of the machines used in industry and building utilise equipment operated by hydraulic pressure. In aircraft, missiles and spacecraft, hydraulic power is used to open and close valves and operate landing gear. In a hydraulic system the fluid, or gas, is confined so that a small amount of pressure applied to it at one point is immediately transmitted to all other points. The illustration below shows this happening. If a 20 Kgm. weight is acting on an area of 1 square centimetre, then a pressure of 20 Kgms. per square centimetre is distributed throughout the chamber. This principle is the key to using a liquid, or gas, to transmit a force from one point to another. Very great force can be

HYDRAULIC POWER. Effort applied to a small piston is immediately transmitted to a larger piston or 'ram' which is able to lift a weight many times that applied to the small piston.

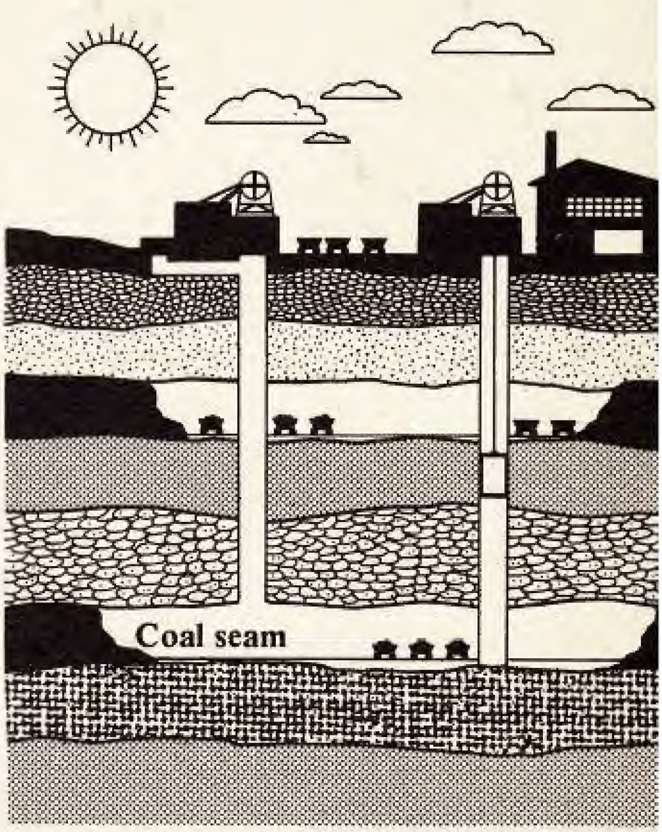


applied by means of a hydraulic piston which is designed to multiply the applied force 2, 3, 5, 10, 50 or more times. For example, if a force of 10 Kgms. were applied to a small piston having a diameter of 1 sq. cm. the applied force would equal 10 Kgm. per square centimetre. If, at the opposite end of the chamber, this force is transmitted to the base of another piston having an area of 40 sq. cms. then the multiplied force would be $40 \times 10 = 400$ Kgms. Thus the large piston would raise a load of 400 Kgms.

Chemical Energy

How were fossil fuels formed?

For us, the sun represents the ultimate source of energy, and much of this energy was locked away in the ground innumerable geological eras ago. The vegetation that grew on the earth millions of years ago took many strange forms that no longer exist today, but one thing all of these plants had in common with present-day plants is something called *chlorophyll*. Chlorophyll is the green colouring matter found in plants. It is a very special substance because it enables the plant to use sunlight to manufacture chemicals important to its survival. Sunlight consists of different wavelengths of *electro-magnetic energy*. Visible light and ultra-violet light are strong sources of radiant energy. When sunlight falls on a leaf, the chlorophyll uses the energy to change the chemical structure of *carbon dioxide* and *water* into *sugar* and *oxygen*. Sugar is a stepping stone to the production of more complex substances called *carbohydrates*. When the trees and plants died millions of years ago and became buried under thousands of tons of soil and rock, the wood and vegetable matter changed gradually into the carbonized substance that we know as *coal*. When this coal is burnt it releases the energy that began as sunlight millions of years ago. Some of this energy takes the form of light but most of it is heat. *Petroleum* and *natural gas* are believed to originate from the microscopic animal and vegetable life that lived in the seas of 600 million years ago. When these animals and plants died and sank to the sea-bed, they became covered with thousands of tons of sediment. Slowly, over a long period of time, the chemicals composing them broke down and were transformed into

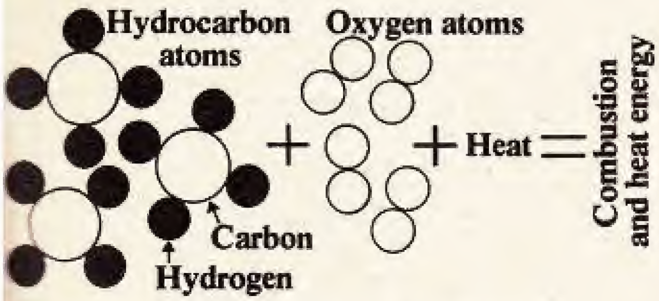


Coal mining.

a complex pattern of hydrocarbon molecules. It is these chemical substances that are drawn from the deep bore holes as crude oil and natural gas.

Why do fuels burn?

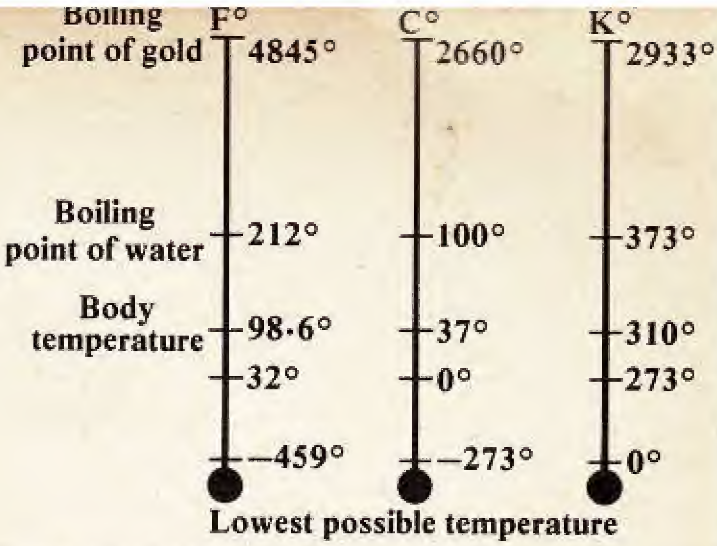
Anything which contains hydrogen and carbon will burn and give off energy in the form of heat and light. This reaction, called *combustion*, is caused by the chemical union of hydrogen and carbon with the oxygen of the air. When this takes place, the original substances contained in the fuel are replaced by new ones. The heat or *thermal energy* is produced when the chemical bonds binding the fuel together are broken by the application of heat. Of course, it is necessary to start this reaction by applying heat, but once the fuel catches fire, it perpetuates itself by burning as long as its supply of hydrocarbons and air holds out. The process of burning is often termed *oxidation* because combustion is made possible by the presence of oxygen.



HYDROCARBON + AIR or OXYGEN
= COMBUSTION
= HEAT and LIGHT ENERGY.

How do we measure temperature?

Temperature is the degree of *hotness* or *coldness* in a piece of matter and these extremes and all points between are measured with instruments called *thermometers*. Thermometers do not measure quantities of heat but only show how hot (or cold) one thing is compared with another. Thermometers and temperatures are used, however, in computing the heat values of different



Fahrenheit, Centigrade and Kelvin temperature scales.

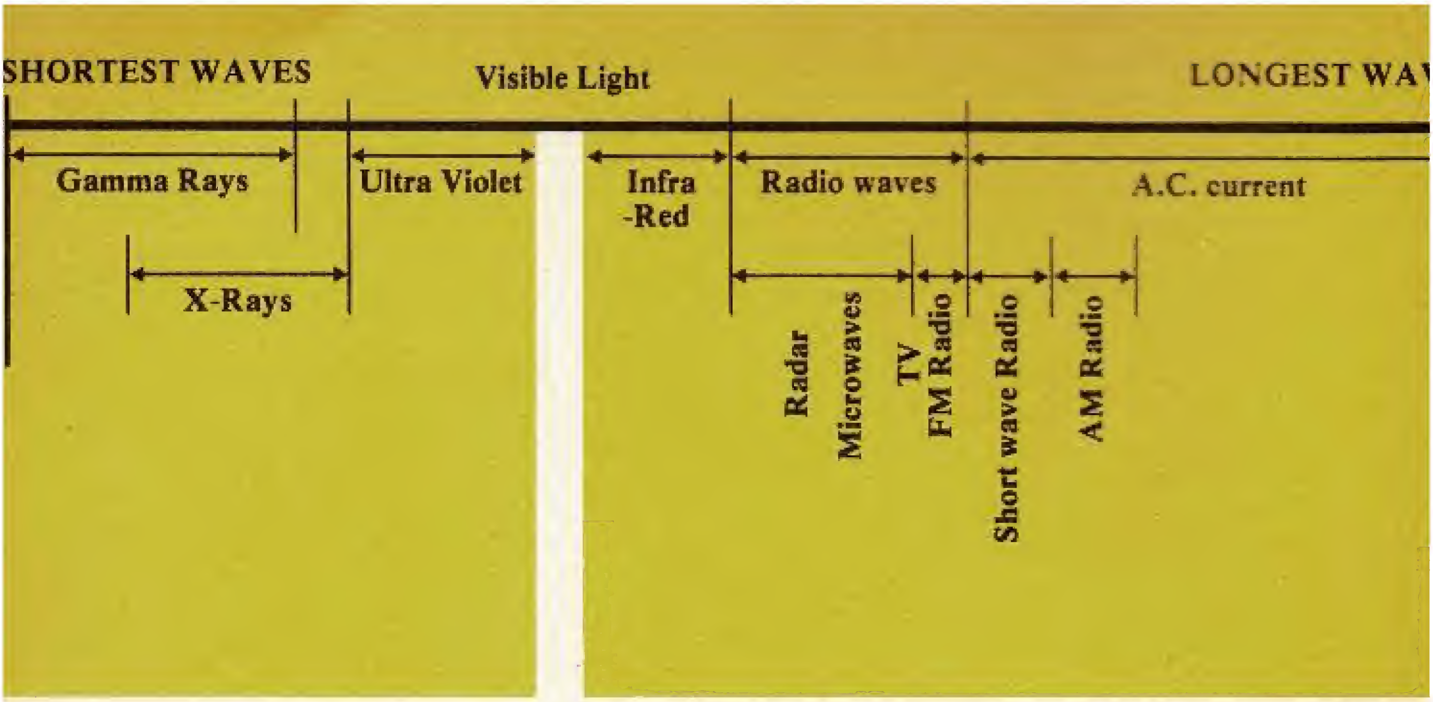
fuels. Three temperature scales are in use today. The *Fahrenheit* scale is gradually being replaced by the metric *Centigrade* scale which is itself often supplanted by the *Kelvin* absolute zero scale. Kelvin starts at the lowest possible temperature, −273°C or −459°F.

What is the heating value of fuels?

All fuels burn at different rates and radiate varying amounts of heat and light energy. For example, we need more paper than coal to boil a can of water in a given time. The heat produced by burning fuels is measured in units called *calories* (cals), in the metric system of measurement, or *British Thermal Units* (Btus), in the British system of measurement. One calorie of heat energy will raise the temperature of one gram of water by one degree Centigrade. One British Thermal Unit will raise one pound of water by one degree Fahrenheit.

FUEL HEAT VALUE CHART

Fuel	*Btu/lb.*	*cal/gm.*
Wood	7,400	4,110
Peat	9,900	5,500
Charcoal	14,544	8,080
Coal	15,720	8,733
Coal Gas	19,220	10,677
Petroleum	19,800	11,000
Hydrogen	62,100	34,500



The spectrum of radiations.

Heat (Thermal) Energy

Caloric: an early heat theory

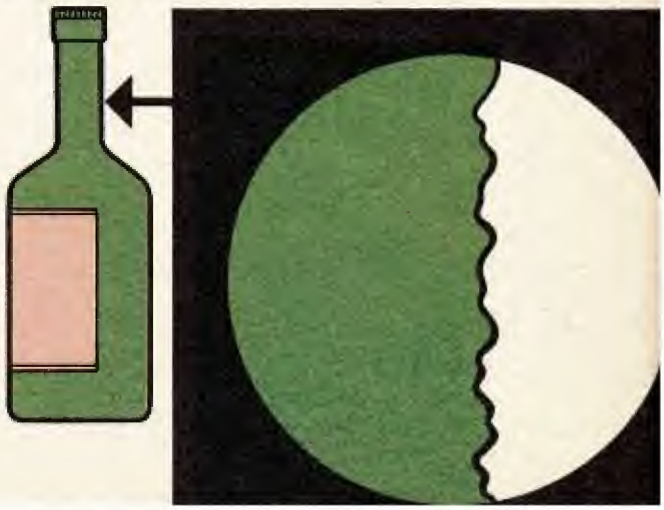
Heat was little understood some 150 years ago. Many peculiar ideas were produced in an attempt to explain the character and properties of heat. One such theory involved the suggestion that all matter was filled with an invisible fluid called *caloric* which leaked out of materials when they were cut, hit, rubbed or drilled. Hence, if a saw blade became hot after it had been busy cutting down some trees, it was stated that it was hot because hot caloric had seeped out from the wood!

Modern theory of heat

You have seen that all matter, solid, liquid or gas, is composed of molecules and even tinier particles called atoms. Each molecule is attached to its neighbour by strong electrical forces generated from within the atom by the orbiting electrons. If you could magnify the surface of any material and examine it closely, you would notice that instead of seeing a smooth surface, the material would be pitted with holes and bumps. This is the outer *molecular structure* of the material—nothing is smooth on the molecular scale! Suppose we were to rub two such surfaces together—what would happen?

The dips and bumps would catch together and dislodge molecules from their positions in the material. Since every molecule and atom is linked 'arm in arm' within the structure of a material by the powerful electric forces of electrons, a considerable amount of

Glass may seem to be a smooth material but 'molecularly' it isn't. Rub your hands or anything else together and heat will be produced from the friction caused by rubbing these uneven surfaces together.



opposition, called *friction*, is produced. When this friction is overcome and molecules and atoms are torn from their 'electronic bonds', the electrons show their 'annoyance' by radiating some energy in the form of an *electro-magnetic wave*.

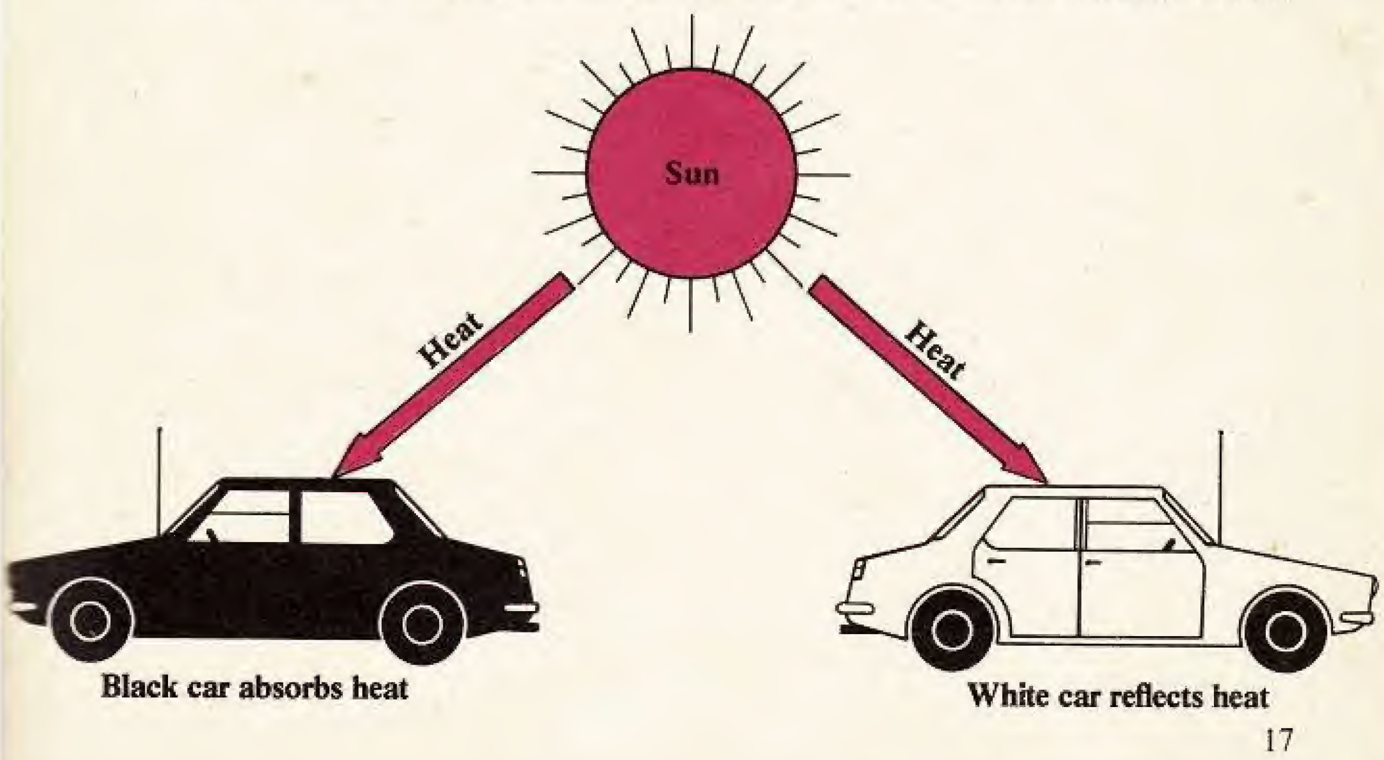
The *Spectrum of Electromagnetic Waves* covers a very wide range of radiations, many of which are familiar to you.

A glance at the spectrum chart (see page 16) reveals just how familiar these radiations are. X-Rays, Ultra-Violet Light (as used by sun lamps), visible Light, Infra-Red (Heat), Microwaves (Radar, TV, VHF Radio), Short, Medium and Long Radio waves—all are electro-magnetic waves. Each of these radiations belongs to a specific portion of the EM Spectrum—each has a particular *wavelength*. The wave-length of radiation emitted by moving electrons depends on the energy level being applied to the molecules and atoms. In the case of rubbing, hitting, drilling and cutting a material, the frictional forces are sufficient to cause the electrons to emit heat (and light, if the friction is very intense). Sometimes, as in the case of setting light to a fuel (or anything for that matter), the applied heat will cause the electrons to become even more excited and to radiate greater amounts of light energy than before. Whatever the stress placed on a material, heat is always generated by the breaking of molecular bonds.

How does heat travel?

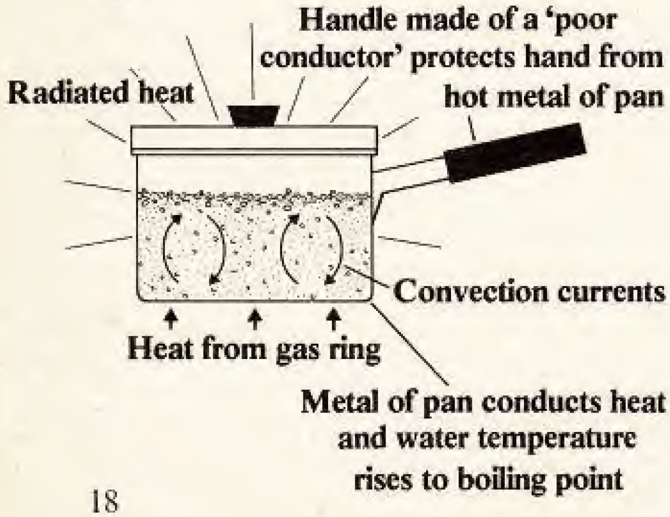
All electromagnetic waves (including heat) travel through empty space (vacuum) by a process called *radiation*. This radiation travels at 186,000 miles per second or in metric units: 300,000,000 metres per second. This speed is slightly less when the wave passes through the air or other gases. When travelling through solids and liquids the speed can be greatly reduced. Some materials *reflect* heat waves back in the direction from which they came. These materials are called *reflectors* and, in the case of heat (and light as well), are usually very shiny or white.

Black paint uses chemicals and oils which absorb more solar heat radiation than the chemicals and oils used by white paint.

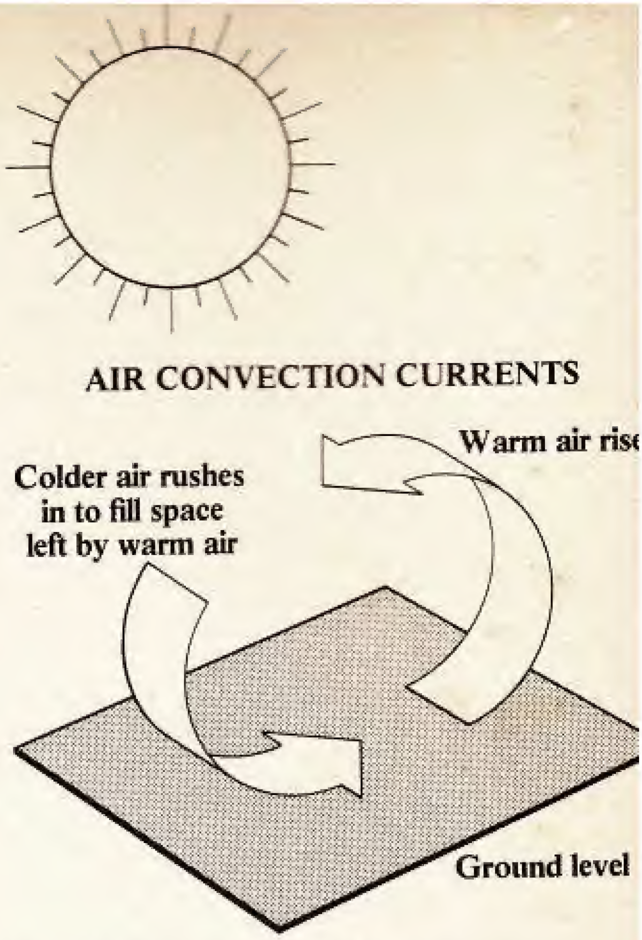


Black painted objects make excellent *absorbers* of heat—they collect heat and get very hot. Metals get hot too, because they are *conductors* of heat. The free electrons, and those still bound to their orbits around the nucleus, vibrate when hit by heat energy and relay the heat throughout the conductor by a process called *conduction* at a speed well below that of direct radiation. There are other materials that are very poor conductors of heat and consequently are extremely good for 'trapping' it. Cork, wool, dry straw, wood shavings and sawdust, fibreglass wool, plastic foam, asbestos and still air, all make excellent *insulators*.

Finally, heat also uses a third method of transportation—*convection*. The best example of convection at work is the earth's atmosphere. The sun heats up the air which rises and lets colder air rush in and fill its place before heating up and rising too. So it goes on. Atmospheric convection is one of the fundamental energy systems of the earth's weather machine. You can also see convection taking place in a beaker of heated water. In fact heat usually travels through liquids and gases by this process, though conduction (and radiation) can also take place.



CONDUCTION. If you touch a hot saucepan handle without a glove for protection, you will soon realise that metal is a good conductor of heat! Different metals conduct at different rates.

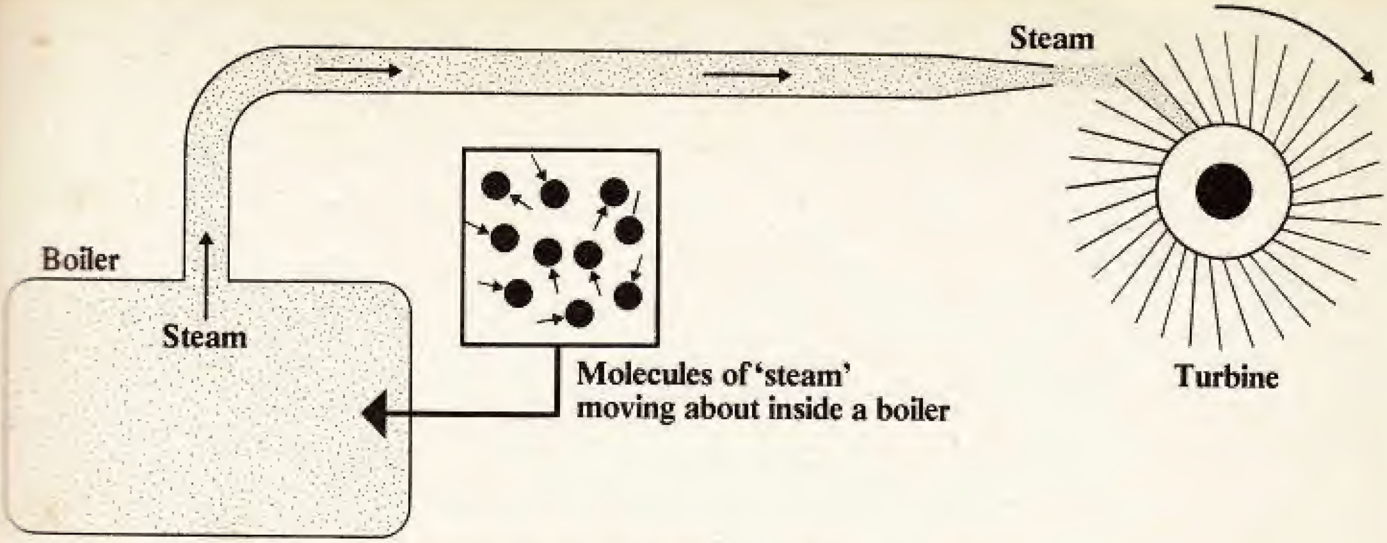


CONVECTION. Smoke rising from a fire shows that hot air rises. Water being boiled over a fire circulates from bottom to top. The earth's surface, warmed by the sun, heats the air closest to it, causing it to rise and circulate. These are all examples of convection.

Whenever heat energy travels through a solid, liquid or a gas, each of them will undergo *expansion*. The molecules tend to stretch the bonds holding them together and if sufficient heat is supplied to a solid or a liquid these bonds will break and the solid will melt. Liquids will evaporate into a gas. We shall read about expanding gases in a moment.

How does heat make a gas expand and perform work?

Each time one gram of water changes into steam it absorbs 540 calories of heat and expands to 1,600 times its normal volume. The 540 calories absorbed by the steam are called hidden heat or, to give it its proper name, *latent heat*. It is obvious, therefore, that a great deal of poten-



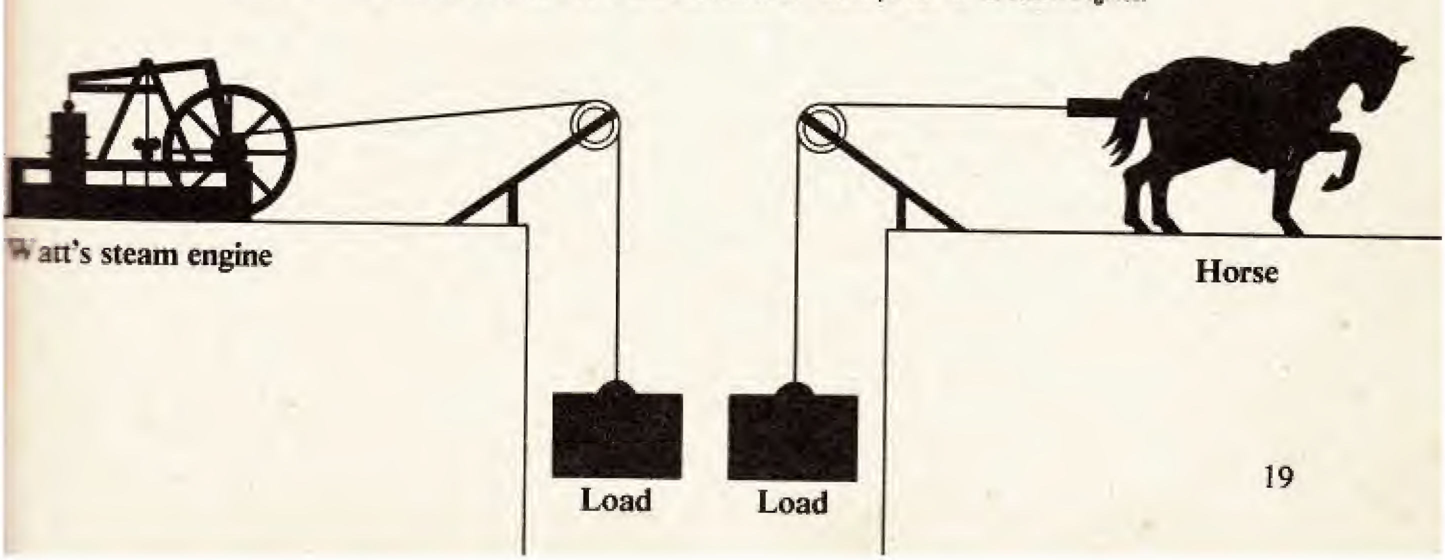
STEAM = MECHANICAL WORK: Steam 'trapped' inside a boiler is 'potential' energy. Steam released from a boiler is 'kinetic' energy and capable of performing mechanical work.

tial energy is locked up inside a steam-engine's boiler. If the steam is forced to occupy less space than it needs for expanding its 1,600 times, its pressure will rapidly increase to a high value. If we could examine the individual molecules of a gas under such pressure we would quickly realise that the entire mass of gas molecules is engaged in a hither and thither motion. The greater the pressure, the more the molecules collide and crash into the walls of the boiler at a tremendous rate of activity. This causes the gas to become hotter and expand still more. When the steam is allowed to escape from the boiler and is directed against the blades of a steam-turbine or released into piston cylinders, a considerable amount of mechanical work is performed by the kinetic energy of the steam.

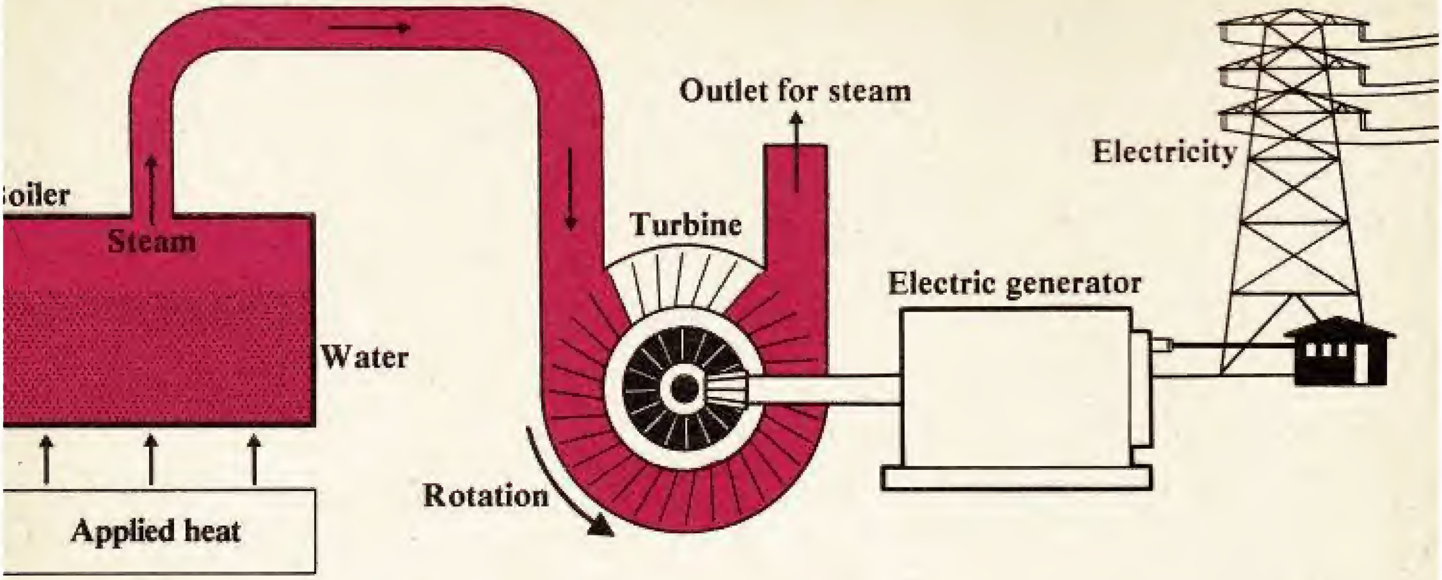
What is horsepower?

Horsepower is a unit of power invented by James Watt, the steam-engine pioneer. Watt wanted to sell his steam-engine to farmers but they were heavily biased in favour of their horses. Watt set out to prove that his engines were more powerful than horses. A horse was coupled up to a rope running over a pulley and descending into a 220 feet deep mine-shaft. The end of the rope was tied to a load of 150 lbs. The horse took 60 seconds to lift this load to the top of the shaft. Watt worked out that if it took a horse one minute to do 33,000 ft.-lbs. of work, one horse-power unit would be equal to 33,000/60 = 550 ft.-lbs. per second.

James Watt used horses to demonstrate the 'work power' or 'horse power' of his steam-engines.



Generating electricity from steam power.



How does the steam-engine work?

Called a *heat-engine*, the steam-engine functions by burning coal in a fire-box placed underneath a boiler. The heat released by the burning fuel raises the temperature of the water and changes it into steam. The kinetic energy of the steam is released into the front portion of the cylinder and then into the rear. This has the effect of pushing a piston (or pistons) backwards and forwards. The to and fro movement of the piston is coupled to a driving shaft which is in turn coupled to a wheel. Thus, as the piston moves backwards and forwards the mechanical drive is transmitted to the wheel and it is made to rotate and perform work.

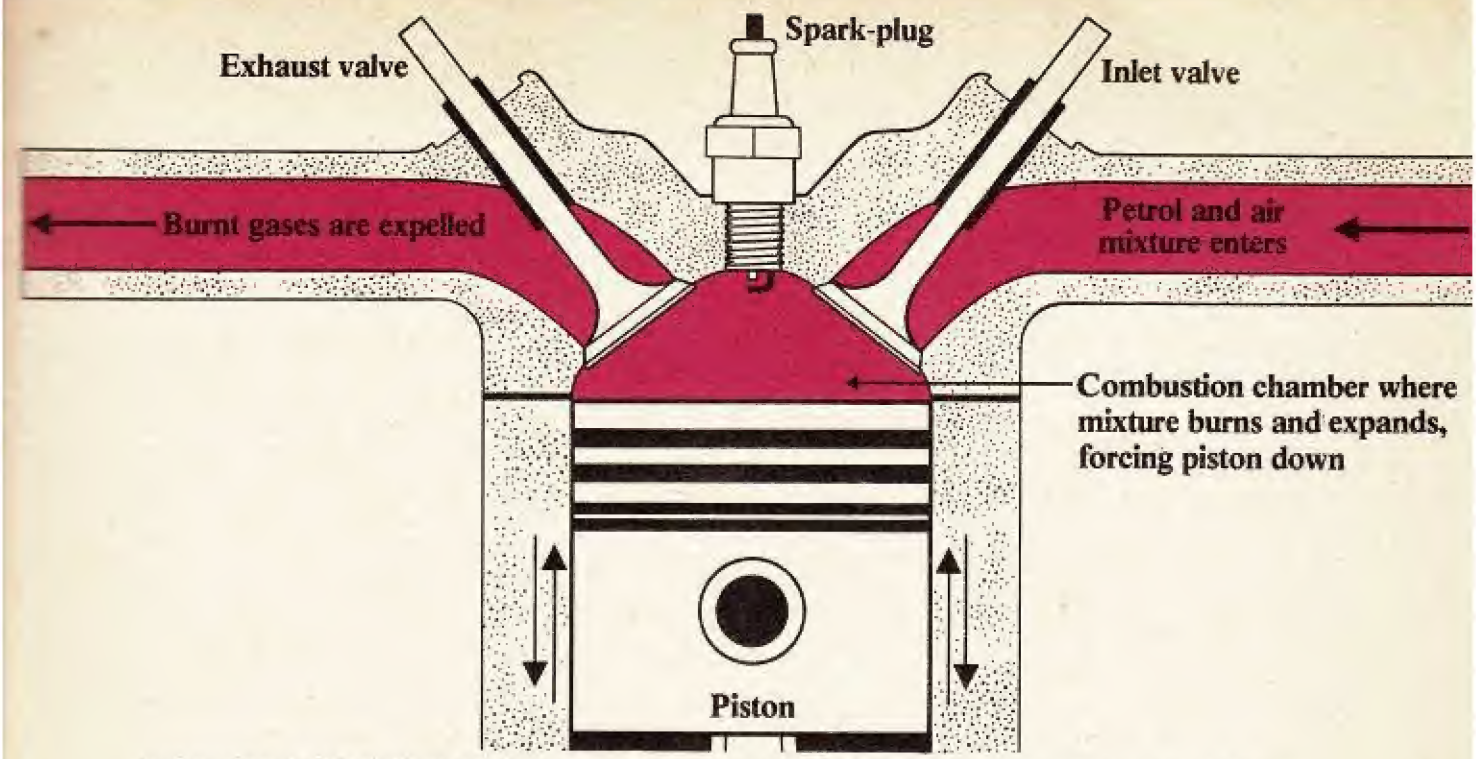
What is a steam-turbine engine?

Another form of the heat-engine, called a steam-turbine, is more efficient than an ordinary steam-engine. The steam is produced as before but this time it is released as a powerful jet which falls on the blades of a turbine. A turbine is merely an up-to-date kind of water wheel. Instead of paddles, this wheel is equipped with strong metal blades set off at an angle and mounted as seen here. The turbine drive shaft is coupled to the shaft of an electric generator. When the high kinetic energy of the steam hits the blades of the turbine it rotates at high speed and transforms mechanical energy into electric power via the generator. Modern steam-turbines are made to withstand steam pressures of more than 2,000 lbs. per square inch and steam temperatures of 500°C. Large installations are capable of producing 70,000 horsepower!

How does the internal combustion engine work?

The internal combustion engine makes use of the properties of expanding gases. Petrol vapour and air are mixed together inside chambers called *cylinders*. These cylinders are equipped with pistons that are coupled to a common crankshaft. The crankshaft is coupled to the wheels or propeller by a drive-shaft and gears.

Each cylinder head is fitted with a device called a sparking plug. These plugs are arranged to discharge a spark of electricity into the gaseous mixture at correctly timed intervals. The ensuing explosions, one following after

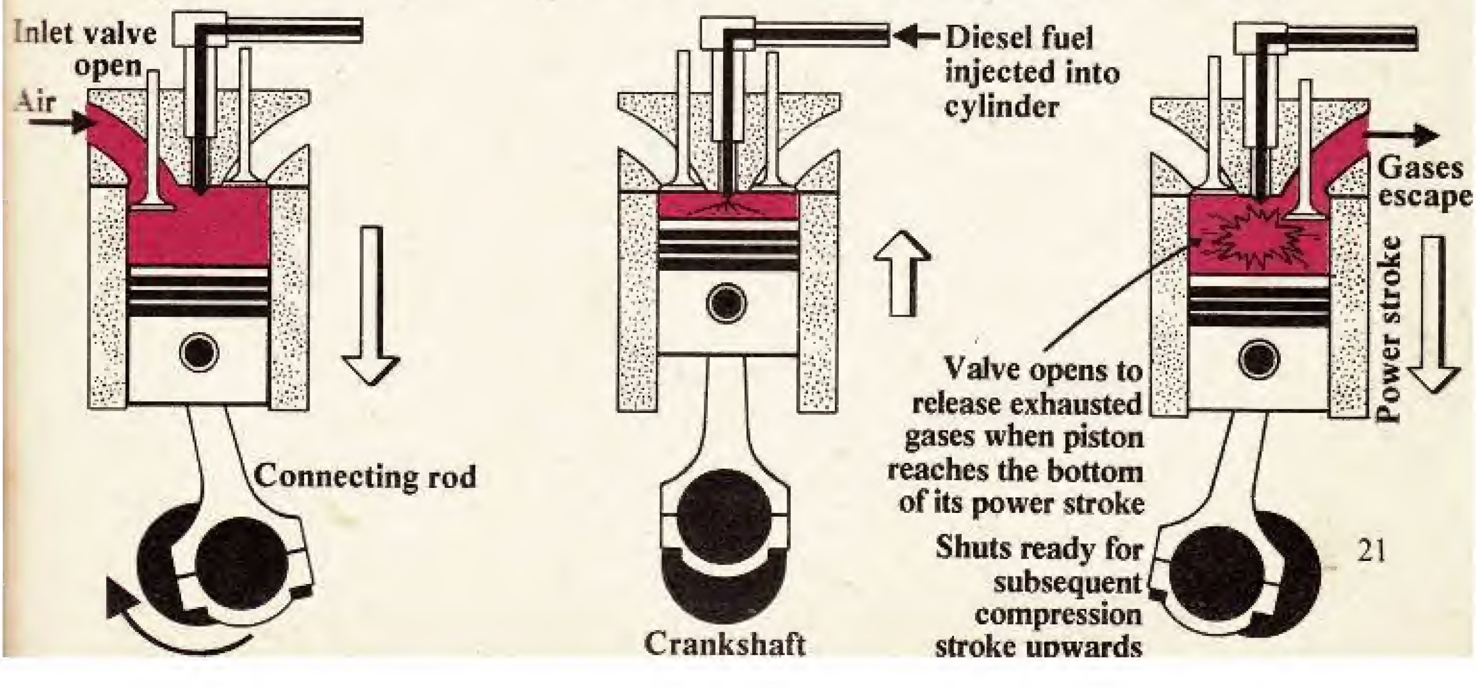


THE INTERNAL COMBUSTION ENGINE. Petrol and air are mixed in the chamber directly above the piston head. When this mixture is compressed by the upward motion of the piston, a spark is used to ignite the fuel, which explodes, delivering a mechanical downward thrust on the piston. This 'power stroke' drives a piston rod which drives a rotary crankshaft coupled to the wheels of a vehicle or propeller shaft of a vessel, machine or aircraft.

another, transmit a mechanical motion to the pistons, which move up and down, cranking the crankshaft and driving the wheels of a car or the propeller of an aircraft or ship.

What is a diesel engine?

The combustion processes in a petrol-engine and a diesel oil engine are different. In the diesel engine, air is drawn in first and compressed to a much greater degree than in a petrol engine. This causes the air to become heated to a temperature of perhaps 800°C. At *this* point a small amount of diesel fuel is injected into the cylinder. Because of the high temperature already existing inside the cylinder, the diesel ignites immediately and a power stroke (the motion made by the pistons and connecting drive rods when energised by the explosion of the fuel) is transmitted to the crankshaft and thence to the wheels, or ship's propeller, via the drive-shaft. (See illustration below.)

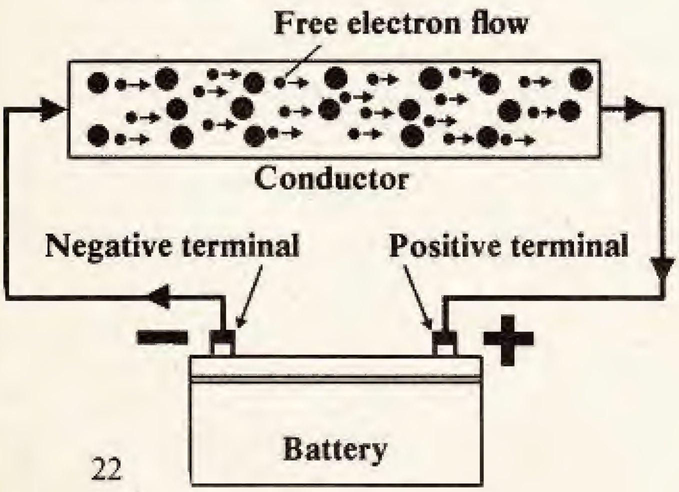


Electrical Energy

What is electricity?

Most metals (gold, silver, copper, tin, brass, platinum, aluminium and mercury) are considered extremely good *conductors* of electricity. Other materials—rubber, glass, ceramic, plastic, dry wood, wax and cloth—do not conduct electricity and are called *insulators*. All conductors possess atoms that permit several of their electrons to wander hither and thither through the conductor—these are called *free electrons*. Any material having free electrons is a potential generator of electricity. As you will recall, electrons are negative particles of electricity, thus a wire connected across the terminals of a battery will permit its free electrons (and those of the battery) to travel through it on their way to the positive terminal of the battery. This flow of electrons is called a *current* of electricity. It is rather similar to our earlier example involving water being stored behind the walls of a dam. The battery is the dam and the electrons, water. The *pressure* of the electrons waiting at the battery's terminals is measured in units called *volts*. The number of electrons passing through a circuit in the period of one second is measured by a unit called the *ampere* or *amp* for short.

The motion of 'free electrons' within a conductor.



What do we mean by the heating effect of an electric current?

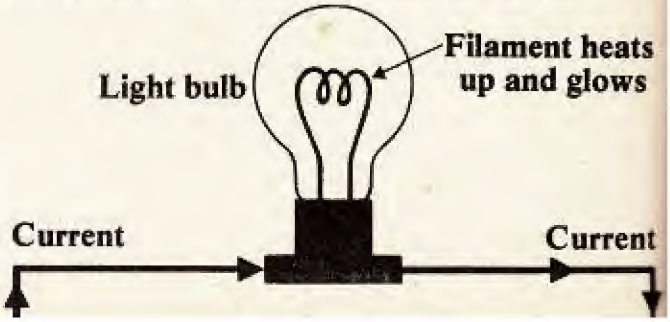
Even good conductors offer some *resistance* to the flow of electrons through them. When this happens we get rubbing and collisions occurring inside the molecular structure of the conductor. In other words, our old friend *friction* has reappeared! Friction, as you remember, causes heat. This effect is used by an electric fire or lamp, in large industrial furnaces and by the ordinary domestic electric cooker. In these examples, engineers have deliberately designed their equipment to exploit *resistance* to produce heat energy, but in other instances they must avoid using high-resistance conductors and parts otherwise they will lose valuable electricity as heat!

How is electric power measured?

In electrical engineering, engineers like to measure energy being used in units called *watts* (w), *kilowatts* (1000w) or *megawatts* (1,000,000w). This is a measure of the rate at which energy is being used; in other words, the *power* rating of an electrical machine or system. Power is measured in watts per second, kilowatts per hour, or megawatts per hour/day or year. For example: the domestic electricity supply is measured in kilowatt-hours (kw.-h.). Thus an electric light bulb left burning for 150 hours would consume the equivalent of 15 kw.-hrs. of electrical power if the bulb were rated at 100 watts.

The British Board of Trade has in fact introduced a unit called the B.o.T.

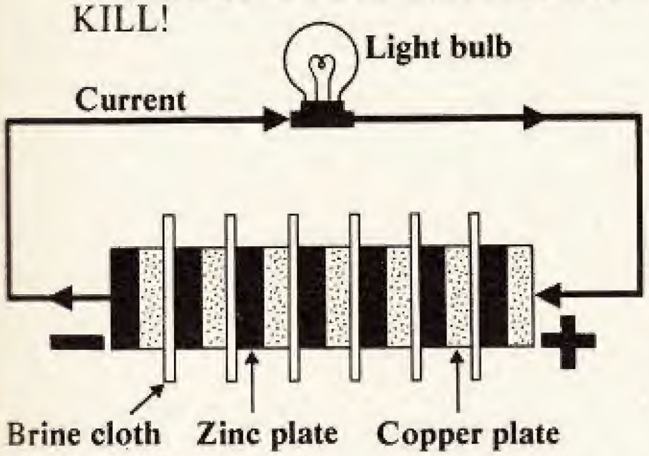
Free electrons (electric current) moving through the lamp filament collide with other atomic particles, bumping each other and producing friction. Friction causes heat and light.



Unit for measuring electrical consumption and 1 B.o.T. unit = 1 kw.-h.

Batteries: chemical energy into electricity

The first proper battery was constructed about 1799, by Alessandro Volta. Called a *Volta Pile*, this battery was made from two dissimilar metals, copper and zinc, laid on top of one another with salt-water moistened linen cloth between each sandwich. Quite large Volta batteries were built and a number of people received serious, even fatal, shocks from them—SO ALWAYS BE CAREFUL WHEN EXPERIMENTING WITH ELECTRICITY. IT CAN KILL!



VOLTA PILE. Try making one out of pennies and zinc washers.

Any metal which dissolves easily into a solution of acid and distilled water (called an *electrolyte*) is said to be highly *electropositive*. This means that the atoms in the metal are chemically attacked by the electrolyte and attracted away from their positions in the metal structure. During this reaction the atoms become positively charged ions because they leave a few outer electrons behind them. Thus the electrolyte becomes filled with positive ions. The 'orphaned' electrons have a negative charge and impart this charge to the metal.

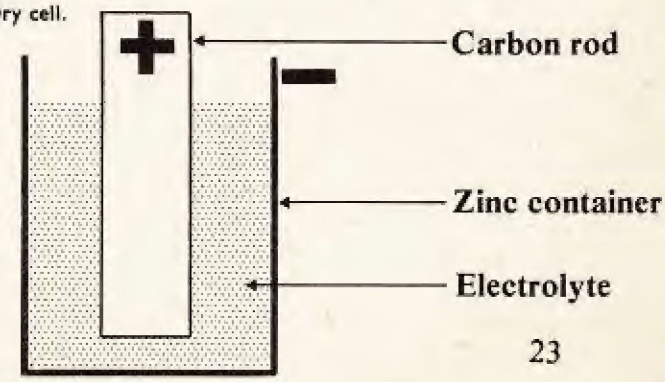
Other metals behave in reverse. They 'steal' positive ions from an electrolyte and so make themselves more positively charged. It may seem confusing to you but these metals are said to be *less* 'electropositive'. The term electropositive means—to give away positive charges *not* collect them!

Scientists have compiled tables of the 'electropositiveness' of the various metals and a few other elements. These give different voltages if they are immersed in a standard electrolyte and measured against a standard electrode. Using a standard electrode made of platinum black wire saturated with a flow of hydrogen gas bubbles, which gives a zero output voltage, we can now proceed by inserting our samples of different metal electrodes one by one and measure their individual output voltages and their polarity (whether positive or negative). The table of electro-positive elements gives an indication of the wide range of output voltages that are available to the cell or battery designer.

Gold	+1·69 volts
Silver	+1·50
Copper	+0·34
Lead	−0·13
Tin	−0·14
Nickel	−0·25
Cadmium	−0·40
Zinc	−0·77
Aluminium	−1·67
Magnesium	−2·37

The simple cells that you buy in the electrical shop today use the same basic principles as Volta's battery. In

Dry cell.

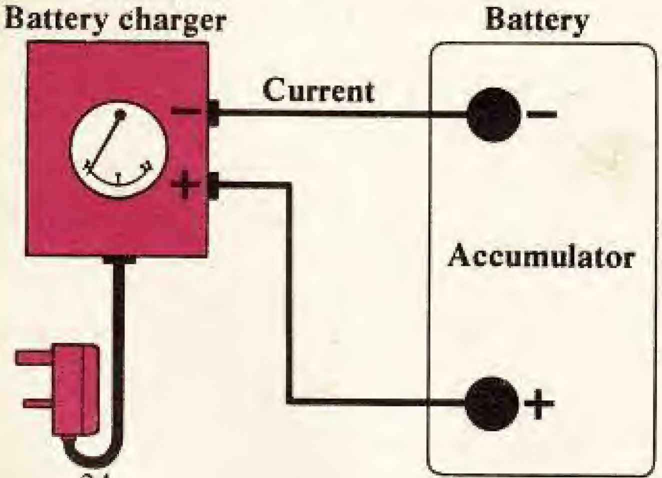


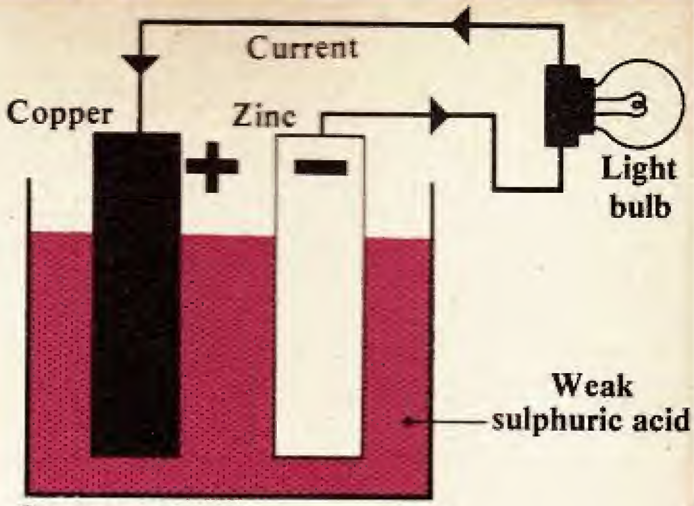
this case the first electrode consists of a zinc container (the negative terminal). A rod of carbon serves as the positive electrode and terminal. Separating these two 'electrodes' is a chemical paste.

The chemical paste mainly serves as an *electrolyte* (pronounced electro light). The paste causes some metals to give up their positive ions and others to collect them and thus in this case the zinc terminal collects a great number of electrons and becomes *negatively charged*. Meanwhile the carbon rod terminal becomes highly *positively charged* (an electrode that is short of electrons and highly attractive to them).

Now, if a small electric lamp is connected across the terminals of this battery, we will see evidence of the electrons flowing through it from negative to positive. The friction in the lamp element causes heat and even light energy to appear. Thus some of the electricity flowing in this circuit is being converted into heat and light energy. This type of cell (or battery) is called a *dry cell* or battery. The word cell is used to describe a battery that only consists of two electrodes. Batteries, like those used in your transistor radio, consist of several *cells* sandwiched together to provide more power.

Secondary cell.





Charging secondary batteries.

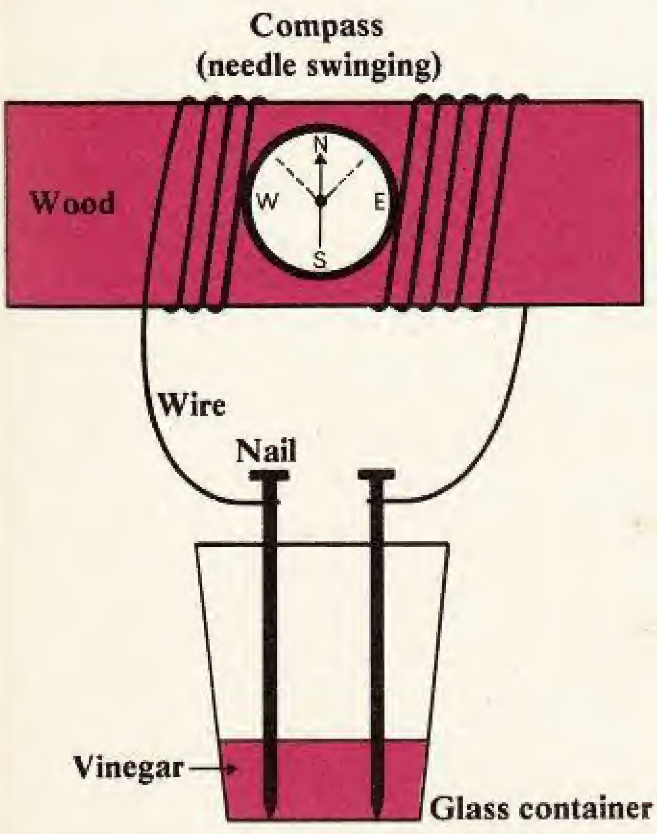
G. Leclanché, in 1865, invented a new type of battery called a *wet cell*. It was the forerunner of the lead acid accumulator as used in motor vehicles. A wet cell consists of two electrodes of dissimilar metal immersed in a solution of acid and distilled water. In the modern accumulator the *negative* plate and terminal is a grid covered with spongy lead. The *positive* plate and terminal is a grid covered with lead peroxide. The electrolyte is sulphuric acid mixed with distilled water. When the two plates are immersed in the electrolyte, the acid attacks the spongy lead and lead peroxide and large numbers of electrons collect on the spongy lead. Meantime, the lead peroxide steals positive *ions* (atoms deficient in electrons) from the electrolyte. The voltage of a wet cell is usually about 2 volts. This cell is able to supply greater amounts of current for a longer period of time than a dry cell can. After a period of time the electrolyte requires restrengthening and provided this is done fairly frequently the wet cell will last a very long time. When the current falls and no more useful power can be taken from this cell, it is not thrown away like its dry cell relative. Wet cells can be recharged with electricity from an external source and then they are once more available for work.

What is a secondary cell?

First you will need a meter. Those of you not equipped with a meter need not worry. Just purchase a very cheap compass from your local toy shop. Fix the compass to a block of wood with some adhesive or transparent tape. Next, wind several turns of single strand wire around the block as shown here, leaving the two ends bared and ready for connection. Now take an orange, lemon, grapefruit or prepare an eggcupful of vinegar. Next, take two strips of dissimilar metal (copper, lead, steel or aluminium nails) and wrap the bare wire from the coil (as shown here) around them and immerse into the fruit or liquid (DON'T EAT THE FRUIT AFTERWARDS!). The moment you dip (or push) the two wires into the acid of the fruit or vinegar, electricity will flow through the coil and cause the compass needle to swing around from its usual position.

Making your own battery experiments

Making a meter and performing simple cell experiments.



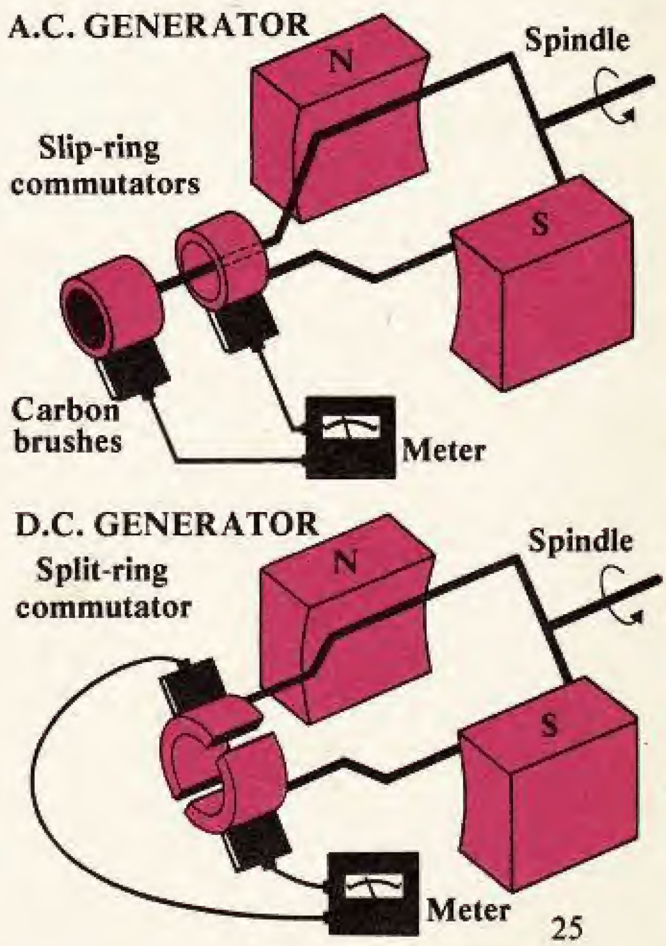
How does magnetism produce electricity and how does electricity make magnetism?

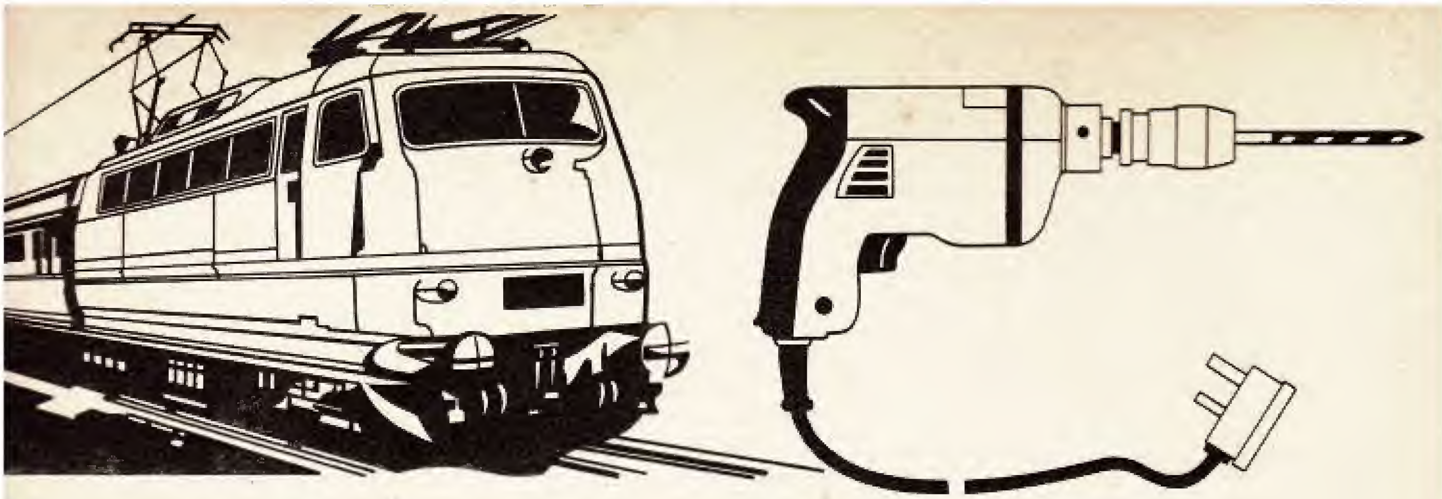
We have just seen an experiment in which the magnetic needle of a compass was moved when an electric current flowed near it. This is in fact how man first discovered that there is a close relationship between electricity and magnetism.

The discovery that electricity could generate its own magnetism and that magnetism could generate electricity led to the development of the electric motor and generator.

There are two kinds of electric generator. One type produces what is termed *direct current* (DC) and the other makes *alternating current* (AC). Essentially the only major difference in the construction of a DC and AC generator lies in the design of its *commutator*. A commutator is simply

AC and DC generators.





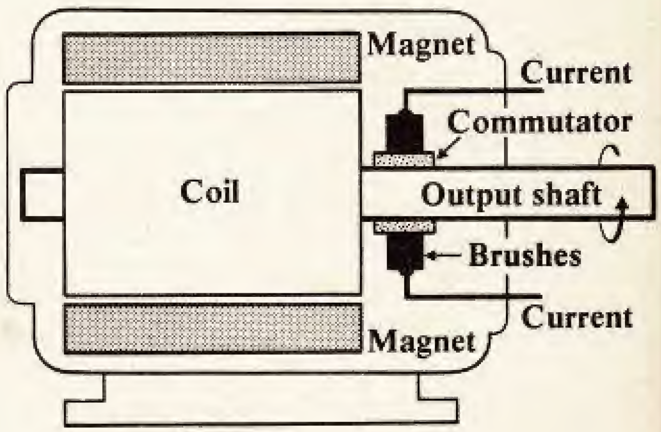
Electric motors find wide application in the modern world.

a metal split-ring or a pair of metal rings, as shown here. The remaining part of the generator consists of a powerful permanent magnet, mounted so that its lines of magnetic force 'cut' across the turns of a coil that is mounted to a shaft, or spindle. When the shaft is rotated by the mechanical force of a heat engine, turbine, or electric motor, the magnetic field cuts across the wires of the coil and causes the electrons within to move, producing a flow of electricity. Because opposite sides of this coil are moving through the north pole of the magnet in one moment and the south pole in the next, the electrons within the wire keep reversing their direction of flow—they alternate the current! Extracting this current from the coil by means of the two single commutator rings provides the user with AC current. If a split-ring commutator is used instead, the brushes taking electricity from the commutator are automatically switched over every half revolution of the coil, thus maintaining a flow of DC current from the generator.

How do electric motors work?

Once we have understood the principle behind the operation of DC and AC generators we can readily understand the operation of electric motors. Electric motors are very important to our everyday life. They perform an infinite number of tasks in industry and other fields. Electric motors convert electrical energy into mechanical energy, such as driving the machine tools in a factory or control systems in aircraft. How do they work? Once again we have a strong permanent magnet mounted so that its lines of magnetism 'cut' a coil mounted on a spindle. If the commutator is a single split-ring it runs on DC current. If the commutator is made up from two slip-rings, it must be fed with AC current. We have already learnt that a coil moving through a magnetic field has electricity induced into it. Now we have a reverse situation. This time we are feeding current into the coil. What happens now? The electrons flowing in the coil will set up their own magnetic field which inter-

Basic parts of an electric motor.

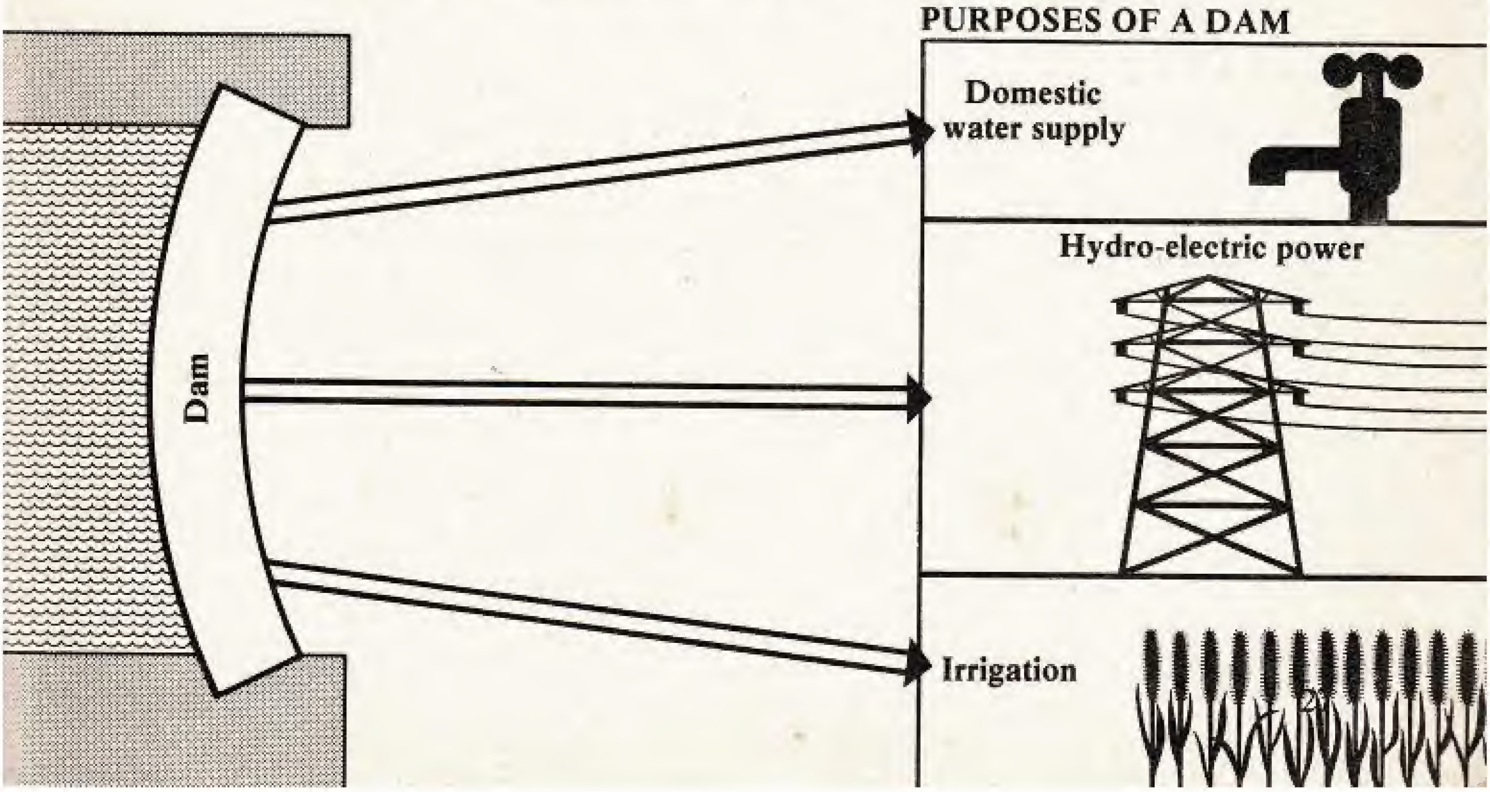


acts with the permanent magnet's field causing the coil to rotate. Thus electrical energy is being converted into mechanical energy.

What is hydro-electricity?

The word *hydro* is the Greek word for water. And a *hydro-electric* scheme is one that utilises water as a means of generating electric power. Well over one third of the world's electricity is generated from the kinetic energy of water falling under the influence of gravity. Huge dams have been constructed across the paths of rivers and valleys. Within a short space of time millions of tons of water, in the form of vast reservoirs, build up against these massive man-made barriers. No other form of 'fuel' has the same qualities as water. As well as being non-diminishing, its cost is lower than any other form of energy, once the initial costs of building the dam and electrical installation have been recovered. In some places, such as India, Pakistan, Egypt, America, Australia and Uganda, the system is associated with large irrigation and drainage schemes as well. The water built up behind the dam is released through pipes at the base of the dam where the pressure is greatest. The kinetic force of the water gushing from these portals of escape is directed onto the blades of banks of water-turbines, the modern equivalent of the age-old waterwheel. The turbines revolve at very high speeds and their shafts turn a series of electric generators. The electrical output of hydro-electric plant can be very great indeed. For example: the Australian Snowy Mountains Scheme, completed in 1974, has a generating capacity of 5,000 million kilowatt-hours annually! Over 90% of the electricity used by Sweden, Norway, Portugal, Switzerland and some South African States is produced by hydro-electric schemes and *still* only a small proportion of the water energy available has been exploited. In Europe, including Britain, about a third of the 'potential' of water-power has been utilised in this way; in America only a quarter, while in Canada, Africa and Russia-Asia the fraction is very small indeed.

Besides generating valuable electricity, dams have other important applications.

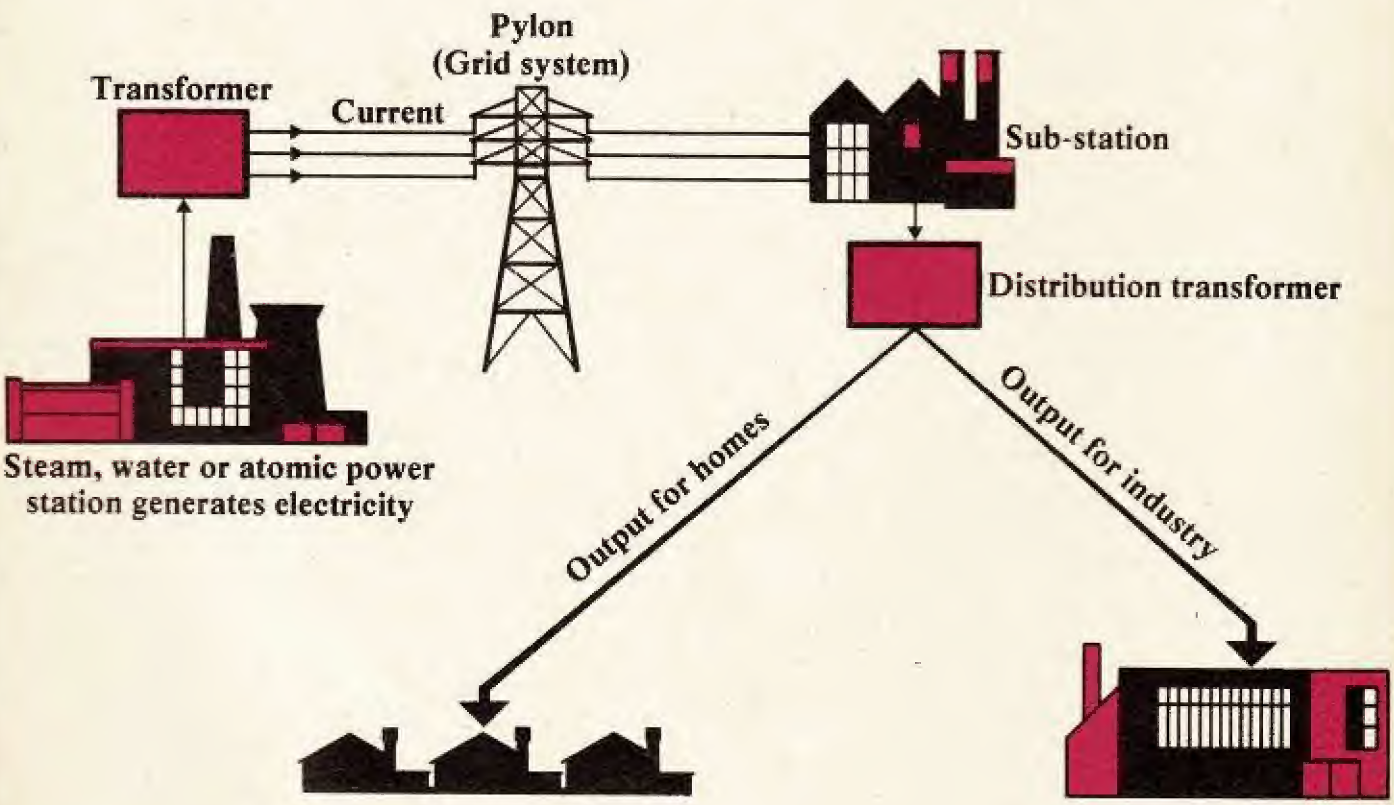


How is electricity distributed?

The electric power generated by power stations, whether steam or water-driven (or atomic!) is distributed by a network of transmission-lines covering the entire countryside. This system is called *The Grid*. We have all seen evidence of the grid as we travel across the country by car or by train. Tall steel towers, many of them over 130 feet high, straddle the land like tall giants marching from one hill to another. The cables they support carry very high voltages, as high as 220,000 volts at a current of 1 ampere. The current is AC, alternating, because it is easier to transmit electricity in this way.

A typical example of a country's Grid System would be as follows. The electricity supplied by the generators is *stepped up* by a device called a *transformer*; if the generator is supplying 220 volts at 1,000 amps, the transformer changes this into 220,000 volts at 1 ampere. The transmission lines of the Grid carry the power all over the country under the watchful eye and control of central and sub-control switching centres. When the power reaches the vicinity of a town or city or industrial complex, it undergoes another *transformation*. This time it is stepped down to different voltages and supply currents according to the users' need. For the ordinary home the voltage is stepped down by sub-station transformers to 220, 120 or 115 volts. Industrial users require considerably higher voltages for their various processes.

The National Grid System: How the nation gets its electricity.

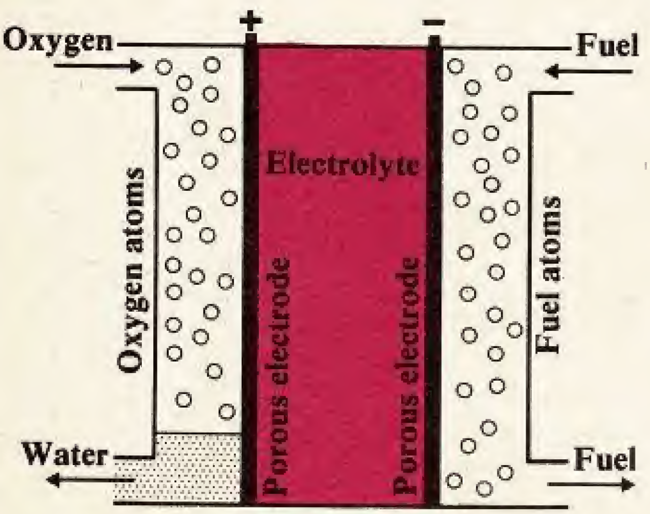


New Methods of Generating Electricity

What are fuel cells?

A great deal of publicity has been given to these devices recently, mainly as a result of their use in spacecraft. However, fuel cells are not new. The first such cell was described by Sir William Grove, in 1842, but the invention was not taken up, probably because of other, more exciting, developments involving steam power. Almost 100 years were to pass before it reappeared. A fuel cell consists of a vessel containing an electrolyte and two porous electrodes (one the negative terminal and the other the positive one). The basic process taking place within this cell is *burning* but not like the burning we see in a fire—rather a slow *oxidation.* The fuel can be a number of gases but hydrogen is often chosen. The other porous electrode receives a supply of oxygen. The electrolyte separates these two gases, making sure no 'direct' combustion occurs. As the reaction begins, oxygen atoms are transported towards the fuel electrode where they give up some of their electrons and make the fuel electrode negatively charged. Water is also produced during this chemical reaction and collected in a separate container. In theory, there should be a chemical to electrical conversion efficiency of 100% but to date only a figure of 60% has been realised. It is not yet possible to name all the reasons why 100% efficiency is not attainable because scientists are still researching into these matters. We still have much to learn about electro-chemistry.

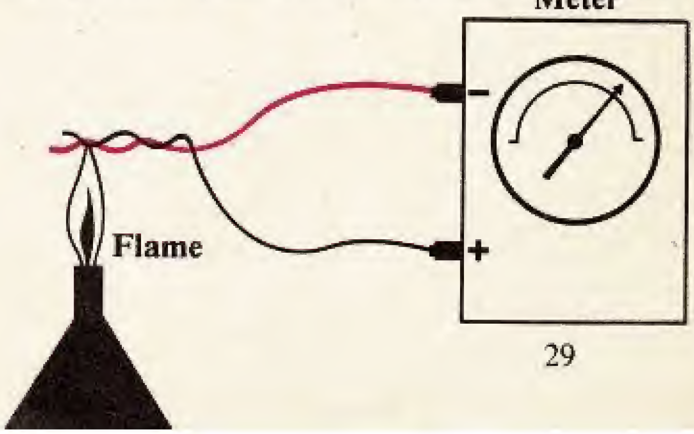
Basic principles of the fuel cell.



What is thermo-electricity?

If we take two wires, one iron and the other copper, twist two ends together and put them into a flame—an electric current will flow from the opposite ends! This device is called a *Thermocouple* and the heat-to-electricity effect is called the *Seebeck Effect.* Until comparatively recent times, thermocouples were only useful as high temperature measuring devices (and low temperature). The invention of the transistor and the existence of high temperature radioactive substances, changed the entire future of the thermocouple. Transistors are devices that were first invented in 1948 and largely replace the valves in most electronic equipment. Their invention has led to the miniaturised electronics of today.

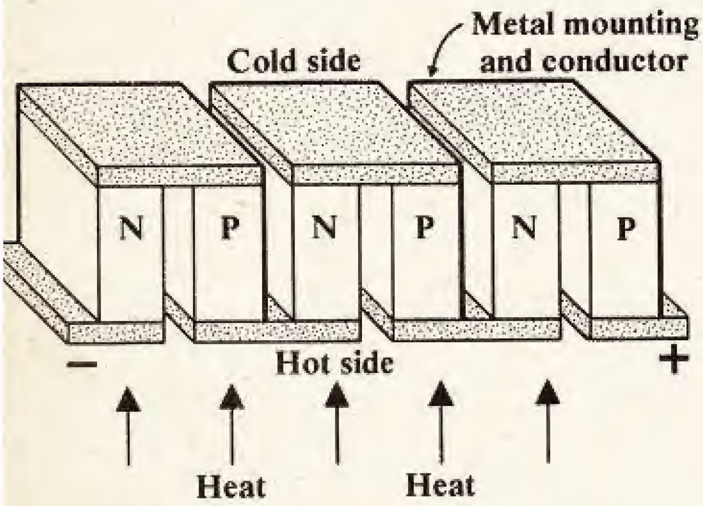
THERMOELECTRICITY: The junction of two dissimilar metals generates small electric currents when heated.



The materials used to fabricate transistors are called *semiconductors*. Two types of semiconductor have been made called *P* and *N* type.

If a thermocouple is constructed from these two types of semiconductor, the electricity generated at the *P* and *N* junction is greater than that obtained from a wire thermocouple. Using the advanced techniques of the electronics industry enables the construction of blocks of *P* and *N* thermocouples.

A solid-state thermocouple.

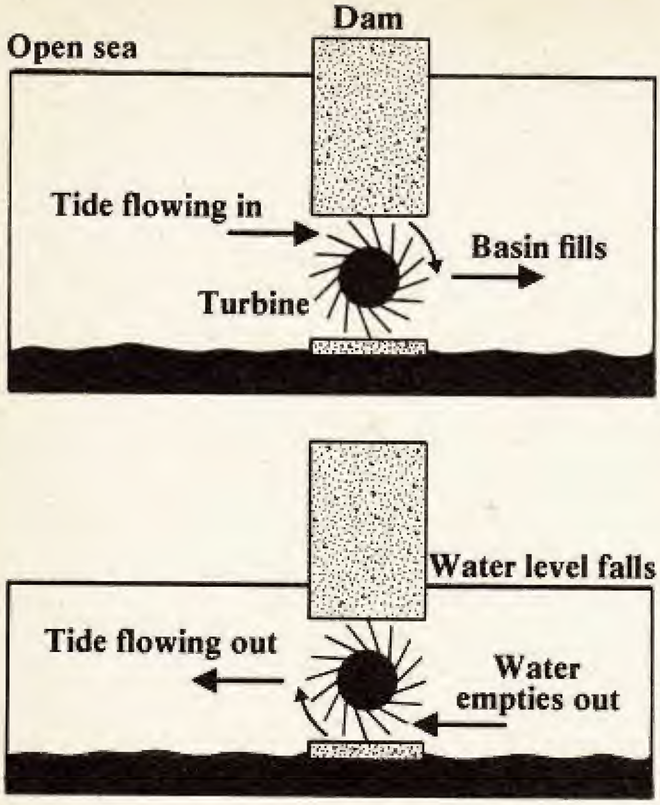


Thus one can have dozens of thermocouples mounted together and covering just one square foot. The electric power available from these banks of couples is of the order of many volts and currents of several amperes can be drawn from them. At this point we must turn to atomic energy to complete the picture. Various materials can be made highly radio-active by leaving them exposed to the powerful radiations of an atomic reactor. Once these materials have been made radio-active they become hot and radiate a great amount of heat. Now, if we were to surround such a source of *free* heat energy with a coat of thermocouples made from semiconductors, we would have a compact source of electricity.

At the present time the efficiency of converting nuclear heat into electricity is only about 15% but scientists hope to double this within the next few years.

How is electric power obtained from the tides?

Since the dawn of history, man has been intrigued and puzzled by the phenomenon of the ocean tides caused by the gravitational pull of the moon and sun. Tidal heights vary a great deal around the world, and in some places, in certain bays and estuaries, the sea's rise is very much more than normally encountered elsewhere. For example, in the Gulf of California at the mouth of the Colorado River, the tide reaches just over 30 feet and at the Bay of Fundy, on the Atlantic coast of Canada, it reaches 50 feet! In the Severn Estuary, in Britain, the tide is more than 45 feet high. Other coastal regions with a high tidal amplitude include Argentina, Australia, New Zealand, Korea and Russia. To date, there has been much discussion about the electric-generating potential of these tidal motions, especially in regard to the sites located in Canada and New Zealand but as yet neither country has gone ahead and constructed Tidal Generating systems. Only one country has in fact gone into this exciting new area of electric-power generation—France. The French Rance River Project is situated on the estuary of the 60 mile long Breton river, about two miles upstream from the medieval town of St. Malo. Here a 2,300 foot dam has been erected with an overall height of 85 feet from the river bed to crest. Twenty-four horizontal-axis turbines are mounted into the structure of the dam. These machines are combined with an electric generator section and will generate electricity on both the ebb and flood tides. Therefore they



Generating electricity from the tides.

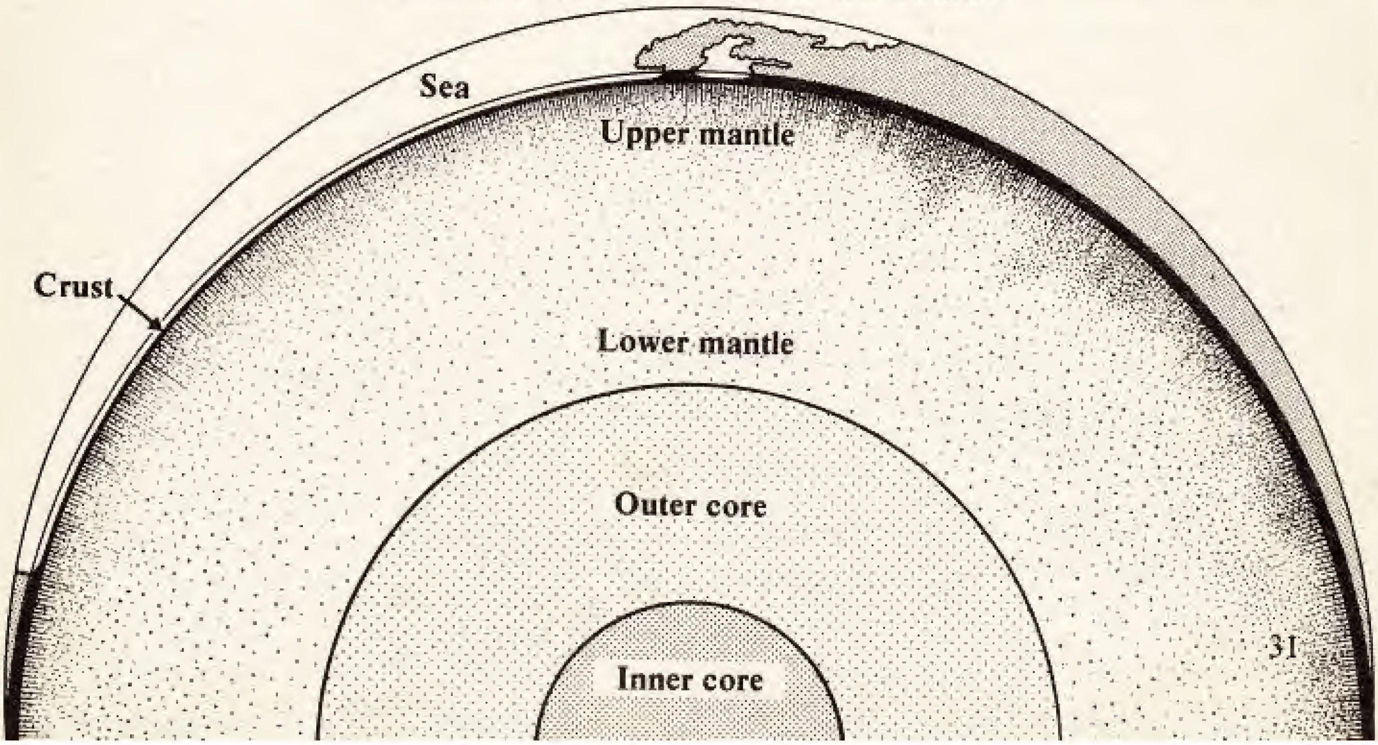
can generate power with water flowing in either direction.

The Rance Tidal Generating Project became operational in 1967 supplying 240 Mwatts of electricity to the French Grid. It now supplies 560 Mwatts.
* Mwatts = One million watts.

What is geothermal energy?

The precise cause of the earth's internal heat is uncertain. One theory suggests that the core is still molten after 4·5 thousand million years. Another plays with the idea of pressure and natural radioactivity. Whatever the real cause one thing *is* certain—the temperature of the rock increases by 1°C for every 100 feet descended! Finally, at the crustal base we can measure temperatures around 750°C. The earth's crust is approximately 25 miles thick over the land and only 5 miles thick under the sea bed. Somewhere in between these levels man mines his minerals and fuels. In addition to these valuable commodities vast quantities of water have also been discovered, trapped for thousands of years below ground and under such enormous rock pressure that it is boiling at 260°C rather than the more normal 100°C. When this water is permitted to escape to the surface (where the air pressure is only 14·5 lbs. per square inch as compared with the rock pressures of many tons per square inch) it flashes over into super-heated steam possessing high kinetic energy.

Geothermal energy (earth's heat) owes its existence to the earth's molten core and to the huge pressures and complex reactions taking place several thousands of feet below the surface.



How is geothermal energy used to generate electricity?

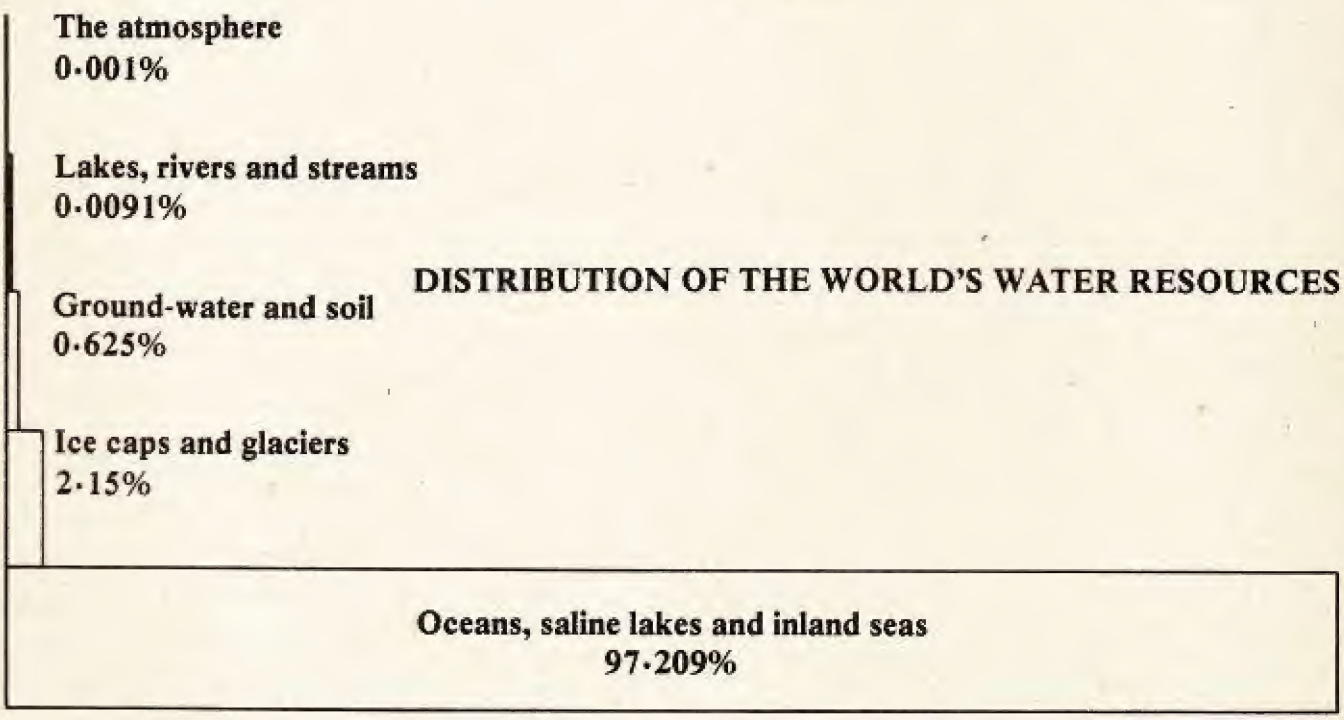
The first scheme to utilise geothermal steam to generate electricity was started way back in 1904 at Larderello, in Northern Italy. Today, this field is contributing some 380 megawatts of electricity to the consumer.

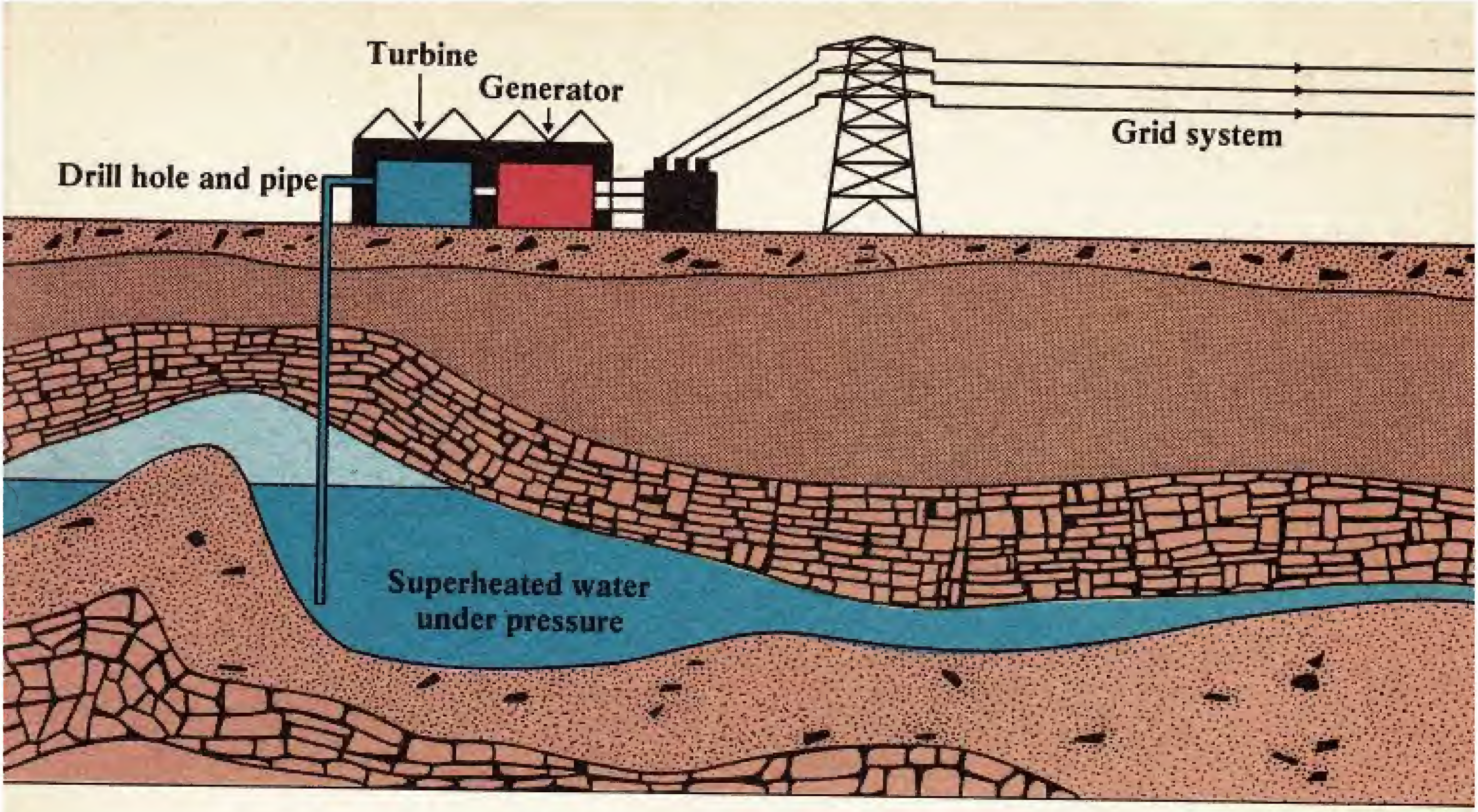
In 1950, the New Zealand government authorized a similar scheme at Wairakei, on North Island. Here there is an active volcano attended by several powerful steam geysers and hot springs. By 1958, the tapped steam was generating electricity. Today, some 300 megawatts are being supplied to the New Zealand economy. During the early part of 1960, the United States began its own geothermal power scheme at a place called *The Geysers* located about 90 miles north of San Francisco. Initially this field was providing approximately 12·5 megawatts of electricity but by 1973 it had been increased to 400 megawatts!

What is the future of geothermal energy?

Once the building costs have been paid for, the running costs of a geothermal power station are a lot less than one that is running on coal, oil, or nuclear fuel. The steam is there, ready made, and waiting to be tapped and used to drive electric-turbines! Many people believe that the vast underground deposits of super-heated steam should be exploited by underdeveloped nations, where the vast majority of deposits seem to be located. For example, recent surveys of Ethiopian resources have revealed massive quantities of geothermal energy—enough to power all of Africa for 50 years! But leaving the power problems of new nations aside just for one moment, the industrialised nations of the world are already suffering from a very serious energy shortage. Demand is outgrowing supply. Should not these countries also make a concerted effort to tap the hidden wealth below their soil and thus, to a large extent, solve their energy problems?

The earth's water resources.





Geothermal steam producing electricity.

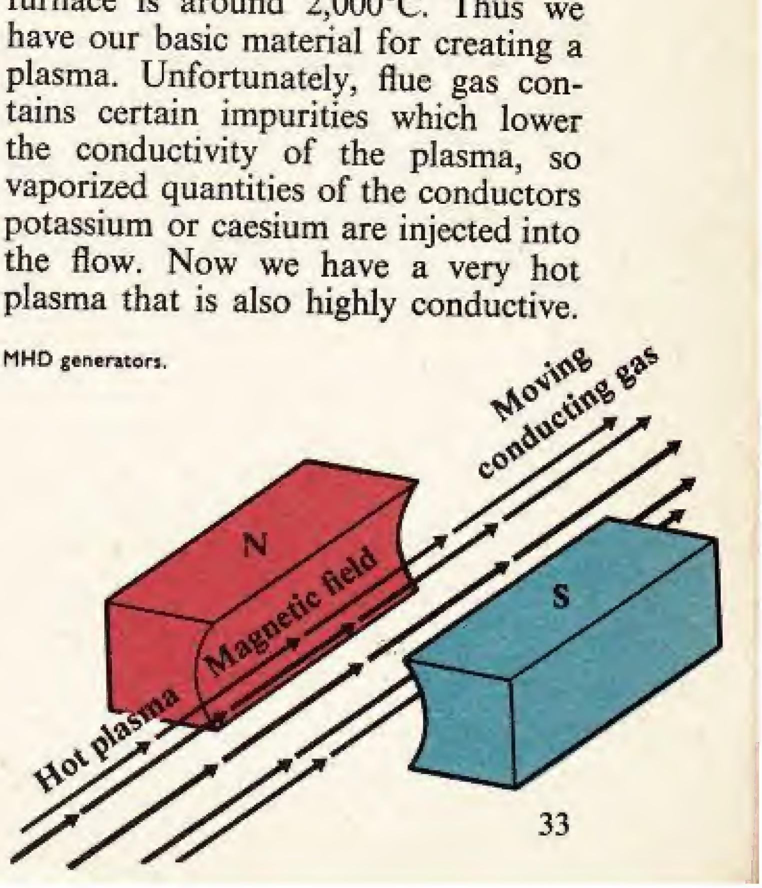
What are magneto-hydro-dynamic generators?

Besides matter existing as a solid, liquid or a gas, there is a fourth state of matter called *plasma*. When a gas is heated to an extremely high temperature it becomes *ionised*. That is to say, all of its atoms lose some of their outer electrons and the gas then consists of free electrons, and atoms with a positive charge, called *ions*. When a gas is made into a plasma it can conduct electricity quite well.

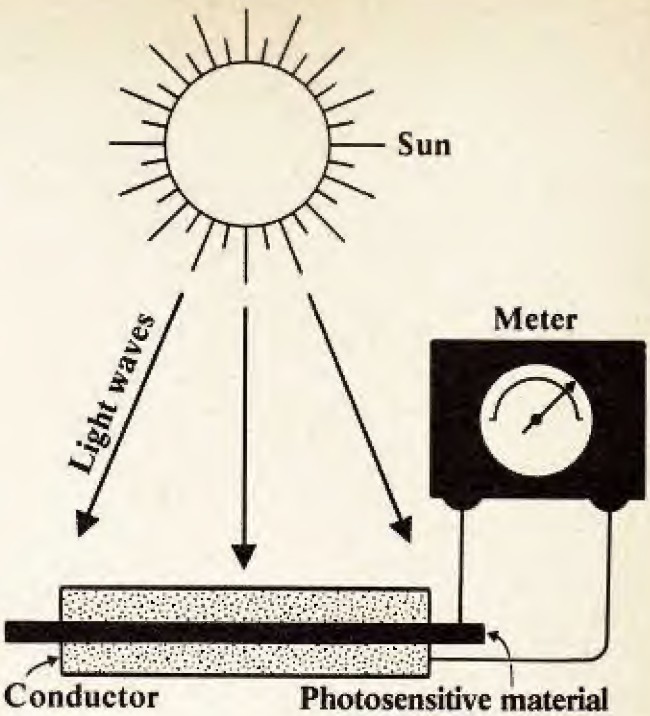
The present energy conversion efficiency of a standard coal or oil-burning power station is just about 40%. That means that some 60% of the heat energy gained from the fuel is going up the chimney! In a world hungry for energy, this state of affairs cannot be tolerated as it once was. Engineers are constantly inventing new ways of re-capturing this wasted energy and increasing the overall efficiency of their energy-producing systems. It looks as though plasmas can help solve this headache. How?

A device called a *Magneto-hydro-dynamic Generator*, or an MHD generator for short, is fuelled by plasma and produces electricity. Now, the temperature of the flue gases rising from a conventional power station's boiler furnace is around 2,000°C. Thus we have our basic material for creating a plasma. Unfortunately, flue gas contains certain impurities which lower the conductivity of the plasma, so vaporized quantities of the conductors potassium or caesium are injected into the flow. Now we have a very hot plasma that is also highly conductive.

MHD generators.



When this plasma is thrust at jet speeds through a powerful magnetic field, electricity is induced into it. If special electrodes are then inserted into the jet stream, the heavy current can be extracted from the plasma. Tests carried out in America, Britain, France, Germany, Japan and Russia show that MHD generators are of great benefit to conventional power station efficiency. Adding the output of an MHD generator to that obtained by conventional means raises efficiency by 15%. Electrical engineers call these machines *toppers* because they 'top up' the output of electric power stations.



PHOTOCELLS. Certain materials produce electricity when they are illuminated with sunlight.

How do we get electrical power from the sun?

One of the most fundamental problems associated with space exploration is that of generating sufficient electric power to run the complicated electronics aboard satellites and space probes. The same problem arises with manned space vehicles. Batteries and fuel cells, plus a few pocket-sized nuclear reactors, have been hoisted aloft and have filled the bill quite successfully. These systems all get heavier as the generating requirement increases, and at this time it has become highly expensive, if not impracticable, to launch very heavy loads. Thus some considerable thought has been directed at improving the device known as a *solar cell*. Solar cells are quite old in the range of 20th century inventions. Before finding application in space they served (and continue to serve) as devices for measuring the intensity or presence of light. They were primarily developed for use as photographic exposure meters. However, as soon as the first satellite went aloft it was plain that *photocells*, as they are also known, had a future up there in space. The principle involving the operation of solar (or photo) cells is simple to explain though complex in terms of atomic theory. Sunlight consists of several forms of radiation. Some of this radiation is particle in nature whilst the remainder is *electro-magnetic*. As we saw earlier in this book, electro-magnetic waves cover a wide spectrum of frequencies and wavelengths—light, heat, X-rays, gamma rays, radio and TV are all members of this family.

When light waves fall upon certain materials they cause the electrons to free themselves from their atomic bonds and produce an electric current. If a thin wafer of this material is placed between two conducting plates, the electricity generated by the light can be tapped and used externally to power something else. Of course, the amount of electricity obtainable from a single cell is quite small, but if huge panels of cells are constructed the current output increases substantially. One of the most publicised solar cell generators was that used by the United States Manned Orbital Laboratory.

The spacemen had to disengage one such panel after it had become stuck and threatened to ruin the planned mission.

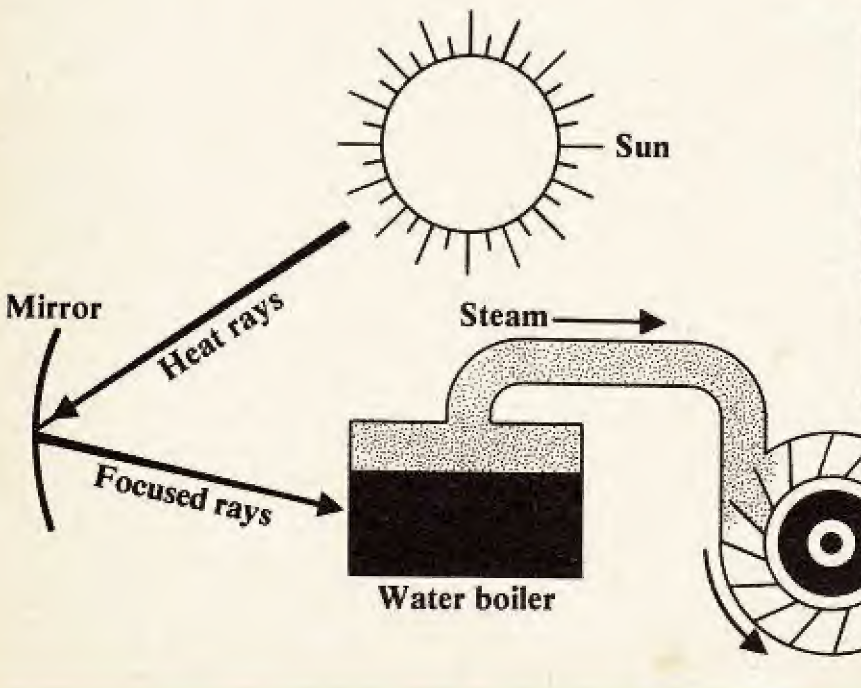
Solar power on earth

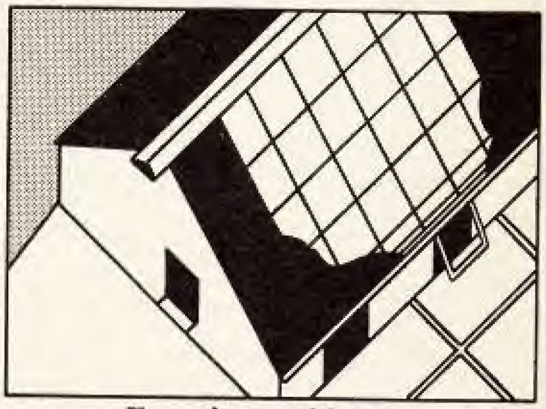
In recent years we have seen various projects attempting to harness the sun's heat to generate electricity. Huge mirrors reflect their captured heat rays into pipes and boilers containing water. The water boils, produces steam, and this is used to drive an electric-turbine. Other experiments use the focused heat to melt metals and other high temperature materials, to study the effects of high temperature. In other words, solar heat has only been put to research purposes to date. No large-scale plants for generating electricity have been undertaken. Yet the energy of sunlight is there for the taking!

During the design of solar cells for space applications, it was necessary to manufacture various filters to cut out heat and ultra-violet light. These radiations will seriously damage the cell and shorten its life. A great deal of knowledge was amassed as a consequence of this research and a new type of cell has emerged—the *heat-cell!* This cell is manufactured in cylindrical form. It consists of an evacuated glass tube with thin films of radiation-selective materials running through its centre (as shown in the illustration).

The first film is made of silicon which absorbs heat energy. This heat is transmitted through the next film which is made of some high temperature working material. The last film, made of gold, returns the heat like a mirror. Thus heat, once it has entered the cell, becomes trapped there and the temperature of the cell rises considerably. If some fluid were to be introduced into the channel running beneath the cell, the heat would be conducted into it, raising its temperature. This is precisely what is done in a large-scale design by American scientists. Long tubular heat cells are bolted together to make mile-long parallel banks of heat collectors. The ends of these parallel pipes are connected to one large feed pipe and, at the opposite end, to a

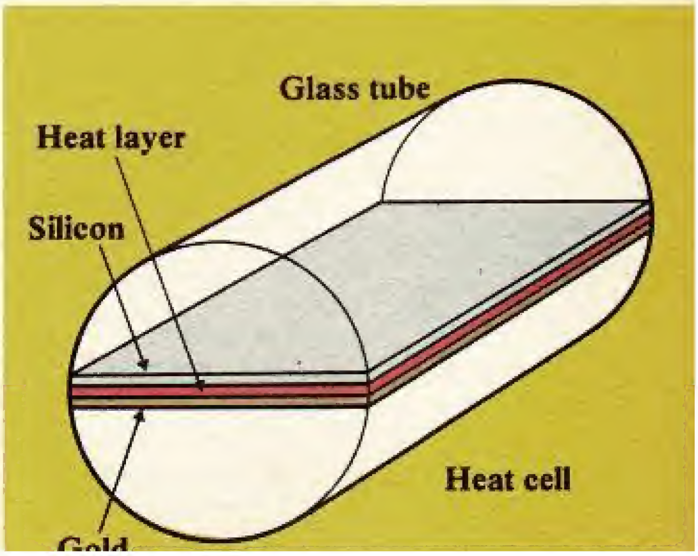
Solar radiation: A newly applied source of energy.




Experimental house contains solar roof tiles used to heat water

Above: U.S. astronauts repairing the 'solar panels' (photo-cells) of NASA's orbital laboratory.

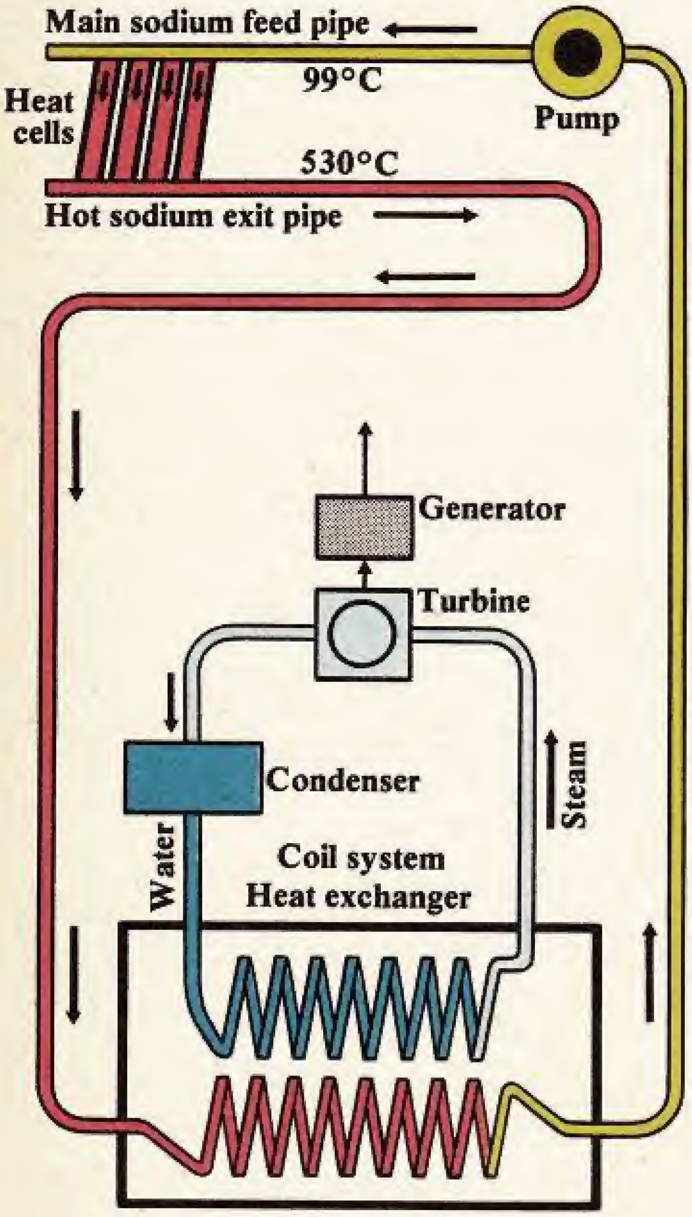
Right: Section of a heat-cell plant.



large fluid-exit pipe. Instead of water, sodium is used as the heat-carrying fluid. This metal melts at 99°C and boils at around 880°C. Since the cell heats up to 530°C, this substance is better than using water, which boils at 100°C.

The heat carried off by the sodium passes through a vast underground heat exchanger which stores the heat and simultaneously transforms water into steam, via a separate coil system. This steam drives a conventional steam-turbine to produce electricity. It has been estimated that a 3 square mile heat-cell plant coupled with a million-gallon heat exchanger could provide 1,000 megawatts of electricity at a heat/electricity efficiency of 53%!

Basic layout of a heat-cell plant.

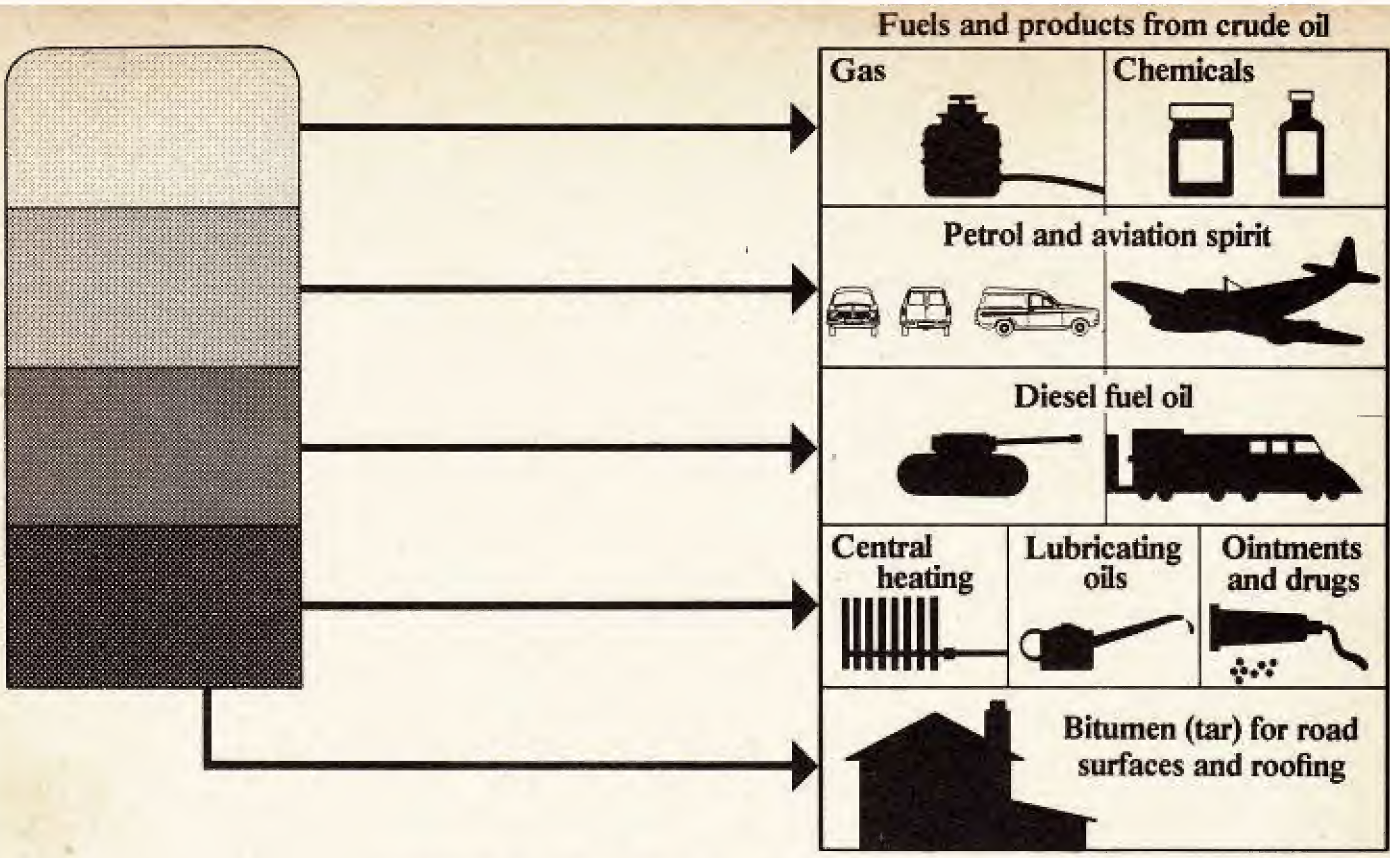


Petroleum—The Fuel of Modern Man

Who drilled the first oil well?

Although as far back as Babylonian times, men collected the small trickles of crude oil which sprang from the ground or rock faces and used it as a medicine and as fuel to light lamps, the proper commercial exploitation of crude oil did not really begin until the first drill struck oil in 1859, at Titusville, Pennsylvania, U.S.A. Edwin Drake, a retired railway conductor, was the first 'oilman', his well hole was only 70 feet deep and provided his employers, the Seneca Oil Co., with 30 barrels of crude oil a day which in turn earned them $650 per day. (One barrel of oil =42 US gallons or 35 British imperial gallons.) Within a few hours of striking oil, 'Drake's Folly' (as it was called by sceptics) was surrounded by hundreds of prospectors and would-be investors. By the end of one year, the whole surrounding area was populated with scores of wooden derricks.

'Drake's Folly'—man's first oil well.



The distillation of crude oil into valuable fuels and chemical products.

Why is oil and natural gas important to our modern world?

What caused this 'black gold' craze? Why was Drake's discovery so exciting and commercial? The story is fairly simple to relate. Drake's employer, an American called Bissell, had read a scientific paper which claimed that if crude oil were distilled on an industrial scale, a whole new range of useful chemical products would become available to man. Not the least of these claims boasted a more satisfactory fuel oil for lamps and heating—Kerosene or (as it is known in Britain) paraffin. Of course, Bissell was not aware of an even greater potential arising from such a distillation process—petroleum! Motor vehicles, aircraft, and diesel-powered ships were still half a century away. Petrol was considered 'waste' during the early days of the oil industry! The method by which petroleum and diesel oil are used to propel vehicles has already been discussed in the 'heat engine' sections of this book. Today's world could not function without petroleum and other crude oil by-products: millions of motor cars, trucks, aircraft, ships, locomotives, furnaces, heaters, machine tools, and petrol-powered utilities rely on this precious fluid. The natural gas too (that is often trapped with the crude oil) is also put to good use—driving the wheels of industry, heating offices and factories, and cooking food.

How is petrol and other fuel extracted from crude oil?

Crude oil is a mixture of light and heavy hydrocarbons—light oils like paraffin and petrol, and heavy oils such as those used to lubricate machinery. Before crude oil can be put to its manifold uses, the light parts must be separated from the heavy. This is accomplished by placing the liquid in a 'fractionating column' which employs different temperatures at which different constituents vaporize and separate.

The chief oil-producing countries are: America, Venezuela, Arabia, Kuwait, Iraq, Persia, Russia, Mexico, Indonesia and Borneo. More recent finds of vast deposits of natural gas and crude oil in the North Sea have assured Britain and her European partners of an oil boom during the 1980's, and still more undersea surveys are being carried out all over the world.

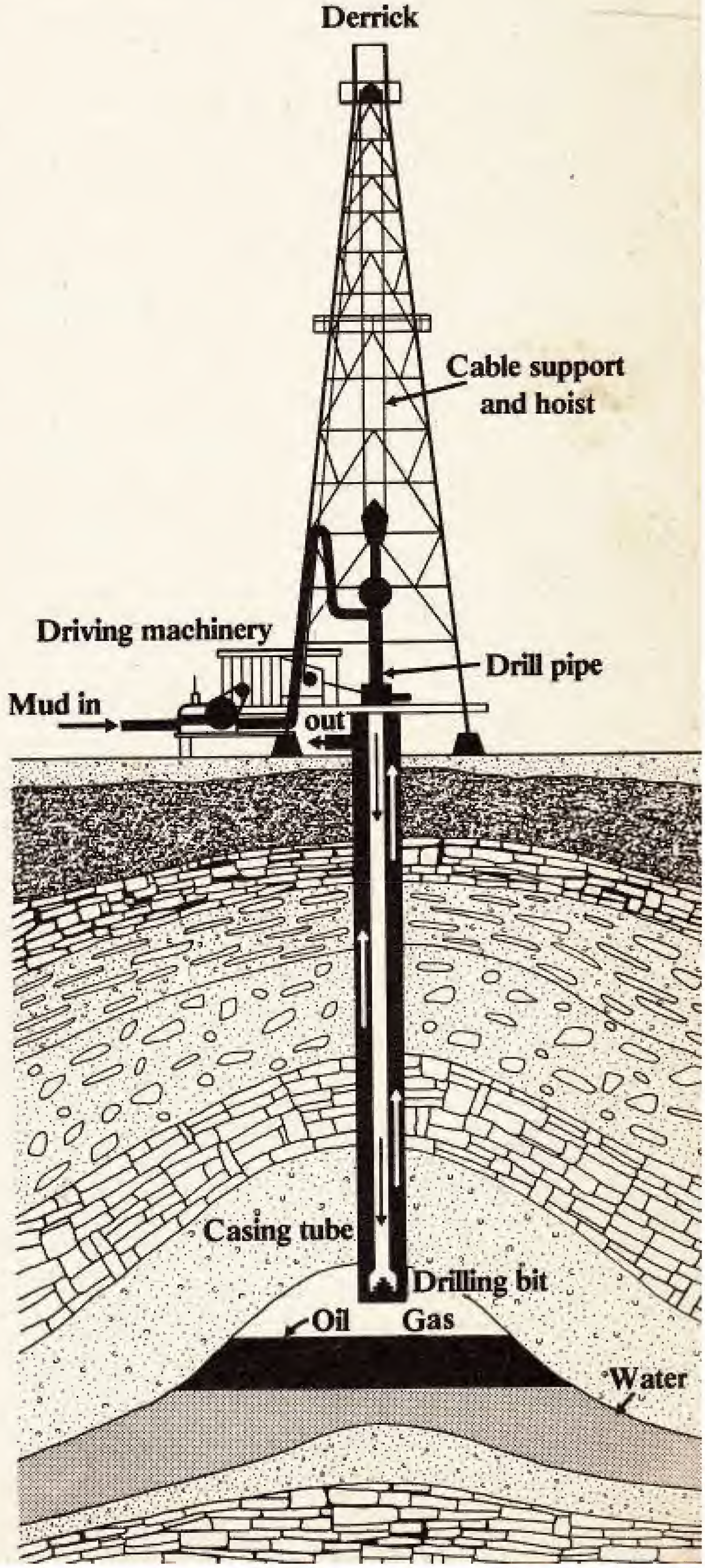
Who are the chief oil-producing countries?

Recent years have seen tremendous changes in the oil industry. Foremost among these is the discovery and exploitation of deposits located beneath the North Sea. Another is the economic power of oil. When the last Arab-Israeli war took place, the Arab oil states decided to put pressure on Britain, Europe and the U.S.A. by cutting oil supplies and increasing the price per barrel. This had a catastrophic effect upon the economies of these nations and many were forced to retract their aid to Israel in exchange for new oil agreements. Even if there were no troubles in the world and we all had access to every barrel of oil that is left in the ground, the demand for this precious commodity will outstrip reserves by the year 2015—that is only 40 years away. If this is an over-optimistic prediction this major calamity could occur before the end of the 20th century!

What is the outlook for gas and petroleum?

So, with this sobering thought in mind, many scientists and engineers are already seeking ways and means of extending the reserves of gas and oil still left in the ground.

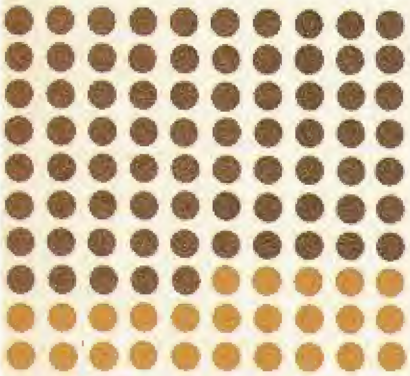
An oil rig. First, the oil company constructs a tower called a derrick. From inside the derrick hangs the drill which consists of a steel bit fixed to a hollow pipe. The pipe is rotated and the bit penetrates deep into the earth's crust. Additional lengths of drilling pipe are coupled up and casing tubes are fed into the hole to prevent its walls from collapsing. Heavy mud pumped into the drill keeps the bit cool, carries rock fragments back up to the surface, and stops high-pressure water, gas or oil from gushing up out of control, smashing men and machinery.



What are isotopes?

In some atoms, such as hydrogen, boron, carbon, nitrogen, oxygen, uranium, chlorine and copper, it has been found that although they possess the correct number of protons and electrons, their individual neutron number varies. To a chemist this is of little consequence since he is only concerned with the number of outer electrons existing within atoms. Atoms of the same element whose neutron count varies from one atom to another *are* of great concern to the nuclear physicist however. Let us examine these multi-personality atoms, or *isotopes* as they are more properly named. For

100 Chlorine atoms

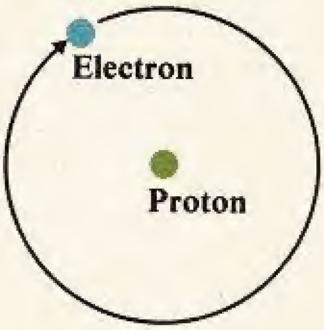


75 Chlorine atoms have 17 protons and 18 neutrons in their nuclei

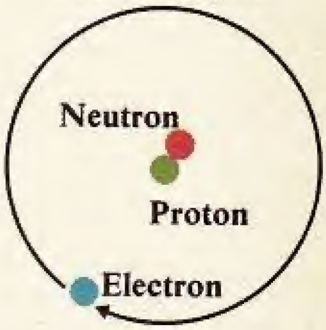
25 Chlorine atoms have 17 protons and 20 neutrons in their nuclei

instance, if you examine 100 chlorine atoms carefully, you would discover that 75 of them have 18 neutrons in the nucleus. The remaining 25 have 20 neutrons at the nucleus. In either case, the 17 protons also living in the nucleus positively identify the substance to be chlorine. Hydrogen is made of two isotopes. Approximately 2 atoms in every 10,000 hydrogen atoms possess a neutron as well as a proton, whereas the other 9,998 atoms only have a proton nucleus. Since water contains hydrogen (H_2O) it should not be surprising if the water that contains the 'heavier' hydrogen atom is called *heavy water* although its proper technical name is *Deuterium*. Heavy water will not harm you if you drink it or wash in it yet it plays an important role in the production of nuclear weapons and atomic energy.

Hydrogen atom

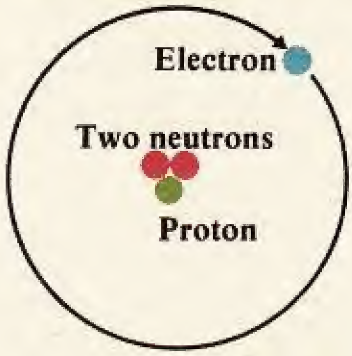


Deuterium atom



What are radio-active isotopes?

Hydrogen can also be changed into a third isotope of itself, by deliberately forcing two deuterium atoms together, at very high speed. This feat is made possible by using a machine called a *particle accelerator* or by using neutrons emitted by a nuclear reactor to bombard deuterium. This new isotope, called *Tritium*, is radio-active. It emits nuclear radiation. Tritium is used in the manufacturing of Hydrogen Bombs.



Tritium atom

Positive particle repelled by first cylinder and attracted by negative

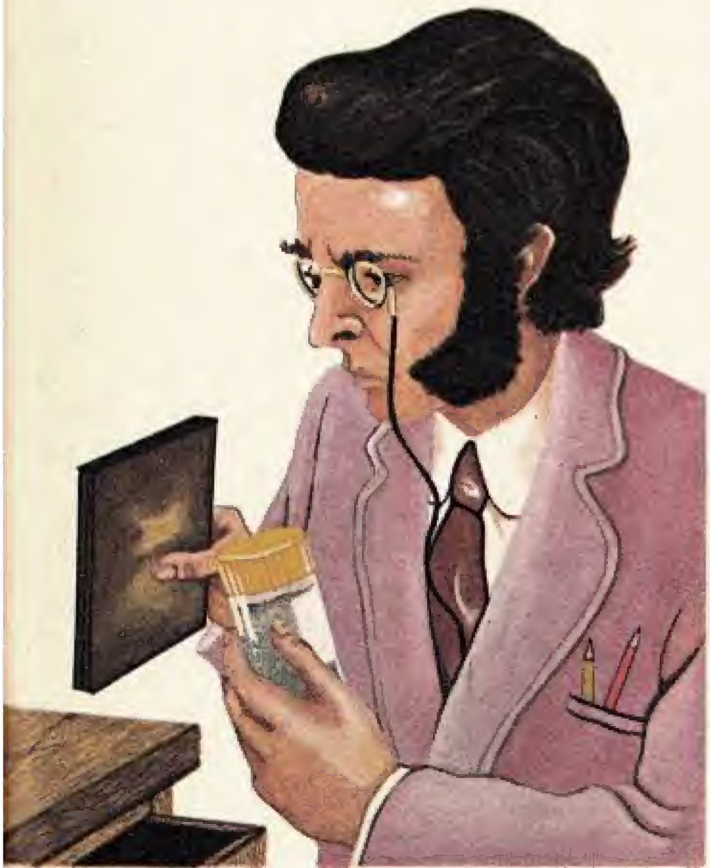
Charges on cylinders now reversed

Particle accelerators are machines that bombard atoms with very high-speed particles. These particles are accelerated down long metal cylinders by a series of tubular electrodes (seen above in a non-straight line). The electrodes are fed with electric charges which 'attract' the particles towards the target.

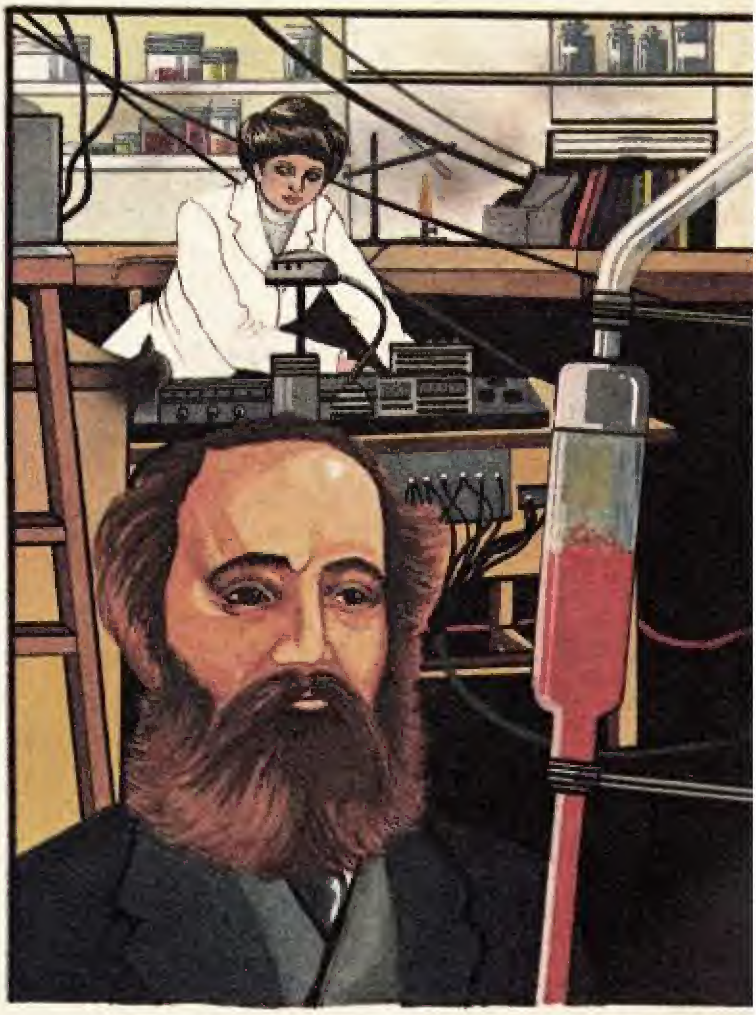
When was radio-activity discovered?

In 1896, Henri Becquerel, a French scientist, became curious over something very strange which had taken place in his laboratory. Becquerel had placed some photographic plates into a drawer in his desk. The plates were well wrapped up in light-proof paper. Several days later when Becquerel came to use the plates he was surprised to discover they had been exposed to 'light'. On further investigation he discovered a jar of uranium salts in the drawer above the one he had placed the plates in. Was this chemical substance emitting light—invisible light? Tests showed this theory to be correct and so, without appreciating it at the time, Becquerel became the first man to discover an invisible form of radiation—one that came from a substance and not the sun or a lamp! Becquerel's work was quickly investigated by scientists all over the world, but two other scientists in France, Marie and Pierre Curie, led the way. These two shared a Nobel Prize in 1903, with Becquerel, for their discovery of the new elements *radium* and *polonium*. The Curies originated the term *radio-activity*.

Becquerel examining his 'invisible' light effect.

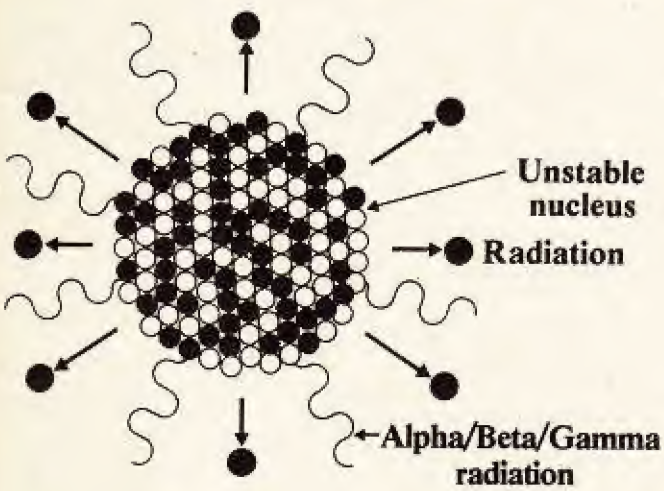


The Curies—discoverers of radium.



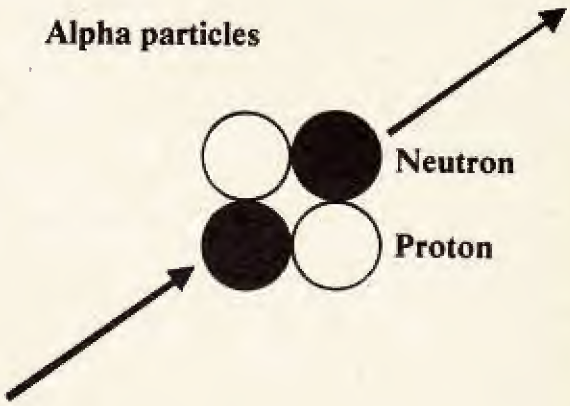
At the beginning of this book, in the section concerning the nature of matter, it was stated that there were 92 natural elements and about 11 other artificially made elements. Each element is identified from another by the number of protons existing within its nucleus. A glance back at Table 1 confirms this. The table also shows the *atomic weight* of atoms and if we subtract the *atomic number* (the number of protons or electrons in a certain atom) from the atomic weight, we shall get a number representing how many neutrons there are at the nucleus. You will see that as the atoms get heavier (higher atomic weights), so, too, the number of neutrons-to-protons increases. We do not understand why, but if more atomic particles are added to a nucleus than it can tolerate, in the form of either protons or neutrons, the atom becomes unstable and starts emitting radiation. Several elements are naturally radioactive in this way, radium and uranium being the most well known of these.

What causes radioactivity?

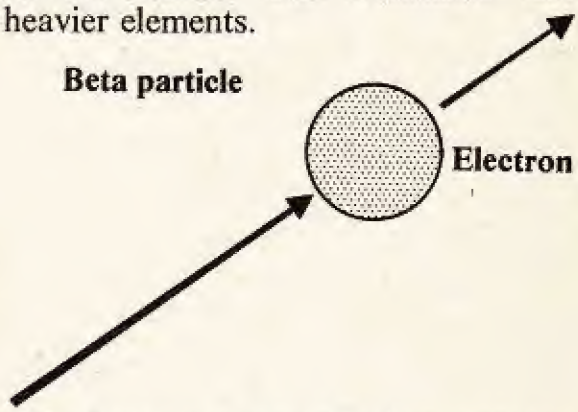


What is atomic radiation?

The atomic radiation emitted by a radio-active element can last for a split second or continue for as much as 4·5 thousand million years (the age of the earth itself!). Radio-active substances emit four types of radiation. These are: *alpha* and *beta particles*, *positrons* and *gamma rays*. Alpha particles are made of two protons and two neutrons bound tightly together (exactly the same combination that is found in the nucleus of helium). Whenever elements emit alpha particles, they are *transmuting* (changing) into a range of lighter elements.



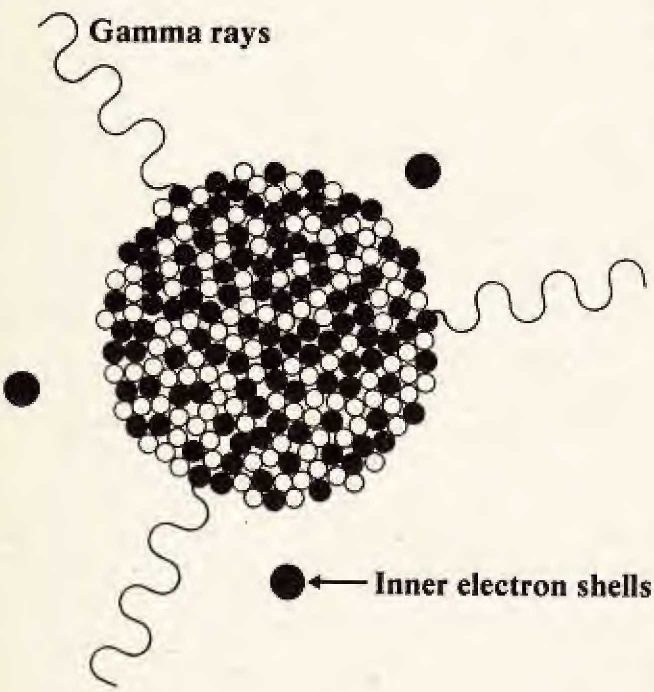
Beta particles are fast-moving electrons. These have amazingly been created by the splitting up of a neutron—the remaining piece left behind in the nucleus is a proton! Hence, beta emitting elements tend to increase their atomic number and transmute into heavier elements.



Positrons are created when a proton splits open and out pops a particle the size of an electron but possessing a positive charge. The other piece of the proton that is left behind in the nucleus becomes a neutron. Hence, positron emission results in the element becoming lighter—it transmutes into a lighter element.

Gamma rays have a different origin. When radio-active atoms emit particles and thus decay or transmute into lighter or heavier elements, they upset the electrons that are orbiting the nuclei. The electron receives a kind of shock every time the mass of the atom changes. This shock or jolt causes the nucleus to emit extremely high frequency radiation. This radiation, like radio waves but considerably shorter in wavelength, is called gamma radiation.

Gamma radiation is believed to be the result of instabilities occurring within the nucleus of an atom which, in some way, upsets the electrical/atomic forces of electrons existing in the shell closest to the nucleus.



What is half-life?

In the course of discussing radio-activity the mechanism of radio-active decay or transmutation was explained to some extent. However what may not be apparent is a factor called *half-life*. If we had about a pound of uranium (which is naturally radio-active) and could weigh it and examine it after a period of 4·5 thousand million years had elapsed, we would notice that only half of the uranium is still radiating as a lump of uranium. After this period of time has elapsed again, half-of-the-half of the remaining uranium will have transmuted whilst the 1/4 remaining is still a lump of uranium. Thus the uranium is decaying with a half-life of 4,500,000,000 years.

As you can see from the chart of uranium half-life, several other radio-active elements called *Daughter Products* decay at various half-life times until eventually practically all that is left is the stable element—lead.

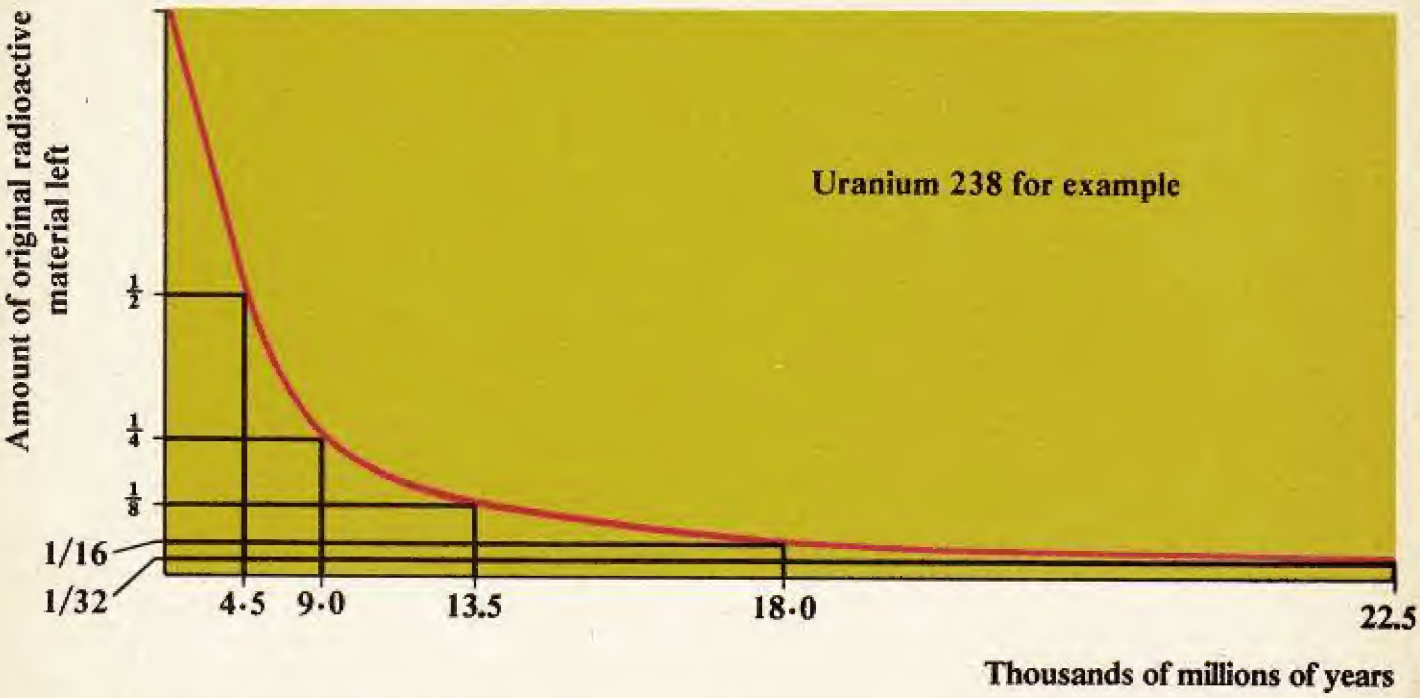
URANIUM TO LEAD TRANSMUTATION SEQUENCE CHART

Isotope	*Half-Life Time*
Uranium-238	4,500,000,000 years
Thorium-234	24 days
Protactinium-234	1·8 minutes
Uranium-234	2,500,000 years
Thorium-230	80,000 years
Radium-226	1,620 years
Radon-222	4 days
Polonium-218	3 minutes
Astatine-218	1·3 seconds
Lead-214	27 minutes
Bismuth-214	20 minutes
Polonium-214	0·00016 seconds
Thallium-210	1·3 minutes
Lead-210	22 years
Bismuth-210	5 days
Polonium-210	139 days
Thallium-206	4·2 minutes
Lead-206	Non-emitting, stable element

All radio-active elements decay into lighter elements until they finish up as stable elements. Thus, after an isotope has decayed one half-life, the amount left decays at the rate of:

$$\frac{x}{2}\times\frac{x}{2}\times\frac{x}{2}\times\frac{x}{2}\times\frac{x}{2}\ldots$$

into infinity.



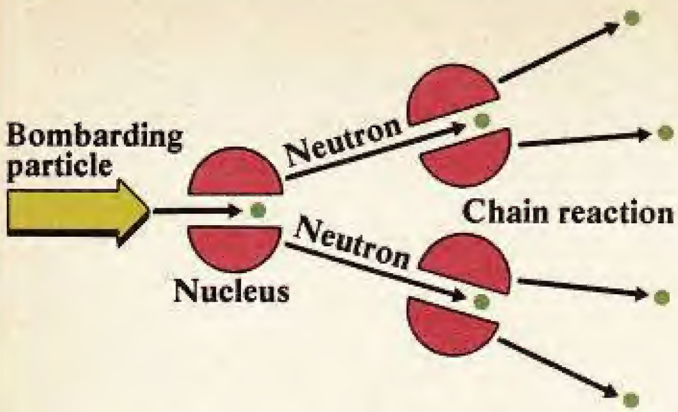
RADIO-ACTIVE DECAY AND HALF-LIFE. Uranium-238 takes 4500 million years for 'half' of its former self to change (decay) into another substance, simultaneously losing 'half' of its former radio-activity. After another 4500 million years, the amount of U-238 remaining is only a quarter of its former self and radio-activity. And so the process continues.

Radio-active uranium: fuel of atomic energy

Uranium never occurs free in nature but is extracted from the minerals pitchblende and carnotite where it shares room with radium. When extracted, the uranium exists in six different isotopic forms, but only two isotopes make up the bulk of the uranium used by man. U-238 (238 is the atomic weight) makes up about 99% whilst U-235 forms about 0·7%. U-238 has 92 protons and the same number of orbiting electrons, as does U-235. The only difference between these isotopes of uranium is in the neutron count. U-238 has 146 and U-235 has 143 neutrons! Both isotopes have approximately 3 neutrons to 2 protons in their nuclei and this results in instability and the atoms become radio-active.

Nuclear fission: tapping the uranium atom's energy

Just prior to the outbreak of the Second World War, the German physicists, Hahn and Strassmann, discovered a vital secret of the atom. They were bombarding some uranium with various atomic particles in an atom-smashing machine when they were amazed to find evidence that some of the uranium was splitting into two lighter elements, barium and krypton. Radio-activity was beginning to be understood and so therefore was transmutation and half-life decay, but this was something quite new—an effect that avoided the usual drawn-out decay lasting millions of years. Elements were being created in a split second by a process called *fission* (splitting).

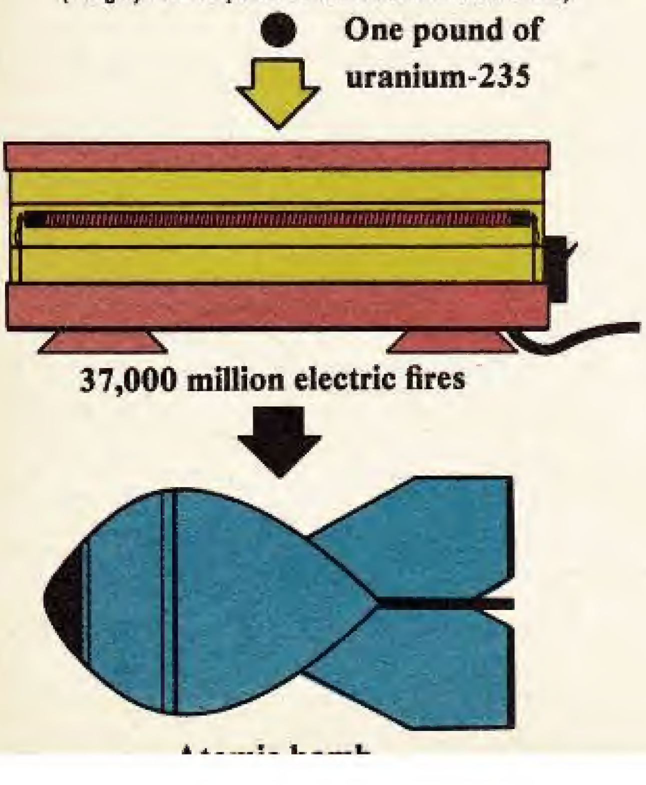


Two other German scientists, Frisch and Meitner, showed that fission resulted in the release of energy. By this time the war had begun and several British and American scientists approached the President of the United States to warn him of the danger of Hitler's scientists developing this discovery into a weapon of terrifying proportions. The race was on.

But you may well ask, "How can the tiny amount of energy released by one fissioning atom lead to an atomic bomb and its dreadful destructive force?" Well, the answer lies in the process of fission itself. If you can collect a certain amount of uranium-235 together, the uranium will undergo a fission chain-reaction that is triggered by the presence of some spare neutrons. These neutrons are either 'spontaneously' released by the uranium or come from the background radio-activity of the surrounding air and ground. Each time an atom is split (fissioned) two or three more neutrons pop out and hit other atoms and split them open. So it will continue until, after only a tiny fraction of one second, the entire quantity of U-235 is involved in a *chain-reaction* of fission. Now this brings us to the energy produced. Each time an atom fissions, it radiates about 0·000000000032 watts of energy—mostly heat energy.

Tiny indeed—but just one pound (453·6 grams) of uranium-235 (about as big as a golf-ball) holds about 1160,000,000,000,000,000,000,000 atoms! If *all* these atoms fission at once, the total energy output will soar to a fantastic 37 million million watts! That is the same as switching on 37,000 million electric fires!

A piece of uranium the size of a golf ball (or ping-pong ball) contains the same amount of energy as would be consumed by suddenly switching on 37,000 million one-bar electric fires! This is equivalent to exploding 9000 tons of TNT (roughly half the power of the Hiroshima atom bomb).



Atomic Piles and Reactors

Atomic piles and reactors

During December 1942 a group of the world's greatest scientific minds were completing the finishing touches to a strange-looking pile of graphite bricks, tubes of metal, and a tank of heavy water. Cables led away to banks of instruments scanned anxiously by technicians and the experts. Enrico Fermi, their leader, made some adjustments to the tubes of metal and waited. Suddenly there was a shout, "It works". Man had built his first operational atomic pile—the colossal heat of fissioning uranium was being produced safely by a *controlled chain-reaction*.

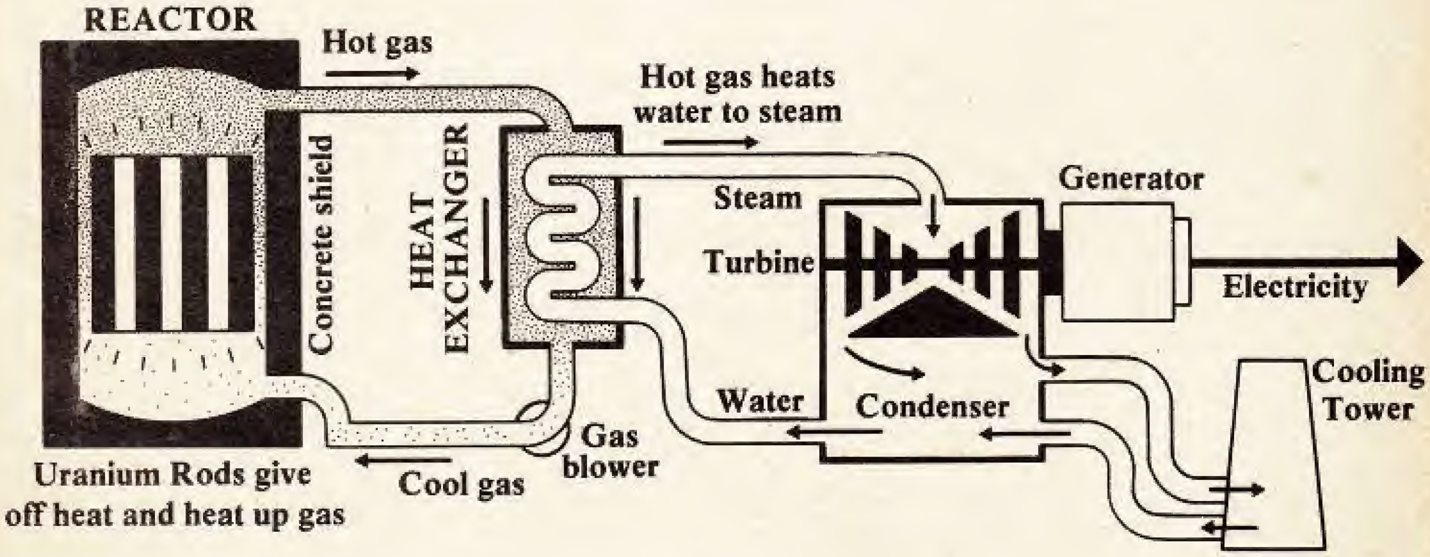
Remote handling of radio-active materials. Most radio-active materials are too dangerous to handle directly. Surprisingly perhaps, uranium and plutonium can be touched with bare hands, but only in their metallic 'non-dust' form.

As already implied in the previous section, U-235 is the best isotope for fission, the only problem being that it is the least abundant (remember only 0·7% of U-235 exists in uranium ore). Thus very complex equipment is needed to separate U-235 from its heavier mate U-238. Whilst U-235 is being separated it is of the utmost importance to ensure that it is stored in small amounts or it will fission uncontrollably. The amount of U-235 that will fission in this deadly way is called a *critical mass*. Atomic piles hold several rods of U-235, sufficient quantity to provide more than the minimum critical mass. So why is there no explosion? The answer is because some of the neutrons, that would ordinarily bring about rapid chain-reaction, are slowed down by the graphite and captured and absorbed by rods of cadmium, that are inserted between the rods of U-235. Graphite, deuterium and beryllium compounds make good *moderators* of neutrons. Thus using sufficient cadmium control rods and moderating material ensures that the chain-reaction taking place inside the U-235 proceeds at a slower rate than that which occurs inside an atomic bomb.

Nowadays, we tend to refer to an atomic pile as a nuclear reactor—terms and descriptions are always changing. A typical design of a nuclear reactor is shown here. The heat produced by the reactor is used to heat water and turn it into steam. From here on we have a normal steam-into-electricity process.

The marvel of atomic energy is that it requires only a few pounds of uranium to run a nuclear submarine all around the world and back. Or a few thousand pounds of uranium per megawatt of electricity generated by a nuclear power station.

Nuclear reactors supply vast quantities of electricity by producing heat from their 'fissioning' cores, changing water into steam and conventionally driving steam turbine electric generators. A gas or fluid circulates the core and transfers the heat through an exchanger which in turn changes water into steam.

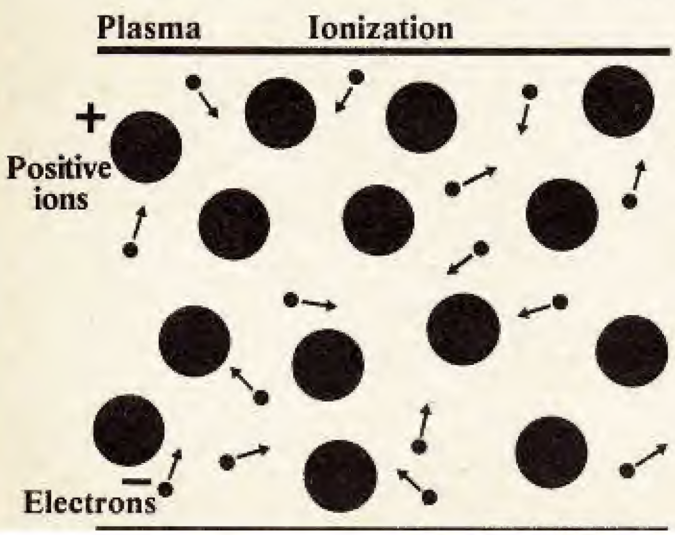


Nuclear fusion—unlimited power for mankind

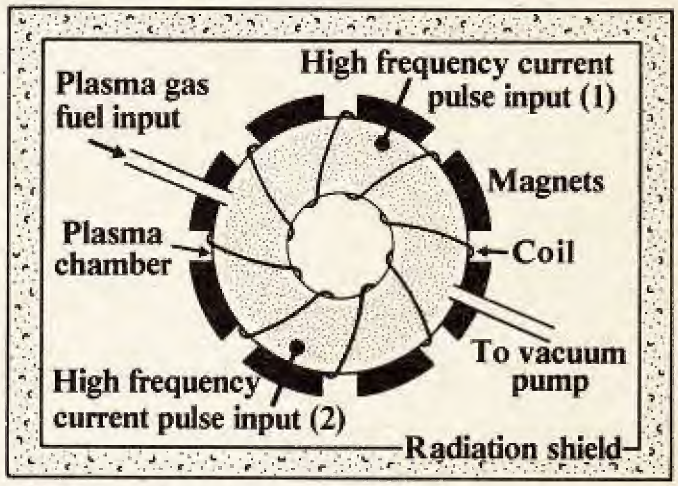
A few years after the ending of the Second World War, the detonation of a new and far more terrible weapon, the Hydrogen Bomb, heralded a new age of energy—thermonuclear energy. Instead of fission, these new weapons use a process called *fusion*. Fusion occurs when light atoms, such as ordinary hydrogen, deuterium, or tritium, are made to collide together at high speed. As a result of these collisions a number of these lightweight atoms *fuse* together to form the element helium. Each fusion releases some energy. This is believed to be the process whereby the sun produces its vast output of energy. On earth we require temperatures similar to that encountered inside the sun, i.e. $1\frac{1}{2}$ million degrees, if such fusion is to be achieved. We have such a source, in the form of a fission explosion. An ordinary atom bomb is therefore merely a detonator for a thermonuclear Hydrogen Bomb!

Fusion reactors: the sun in a bottle!

Because there are estimated to be unlimited amounts of deuterium in ordinary sea water, scientists believe that once they have learnt how to harness the heat generated by a thermonuclear reaction, the oceans will provide mankind with an almost endless quantity of fuel.



Fission seemed to be the only easy way to produce the heat of the sun and use it to cause a fusion reaction. At least that was the story until scientists began experimenting with *plasmas*. Remember: a plasma is the name given to a gas that has been made so hot that its atomic particles become *ionised*. Ionization means that the atoms lose some of their electrons and thus become positively charged. Meanwhile the electrons wander freely about the gas making it a good conductor. Because plasmas are conductors of electricity they respond like a wire or coil does to magnetism. This is the means by which man hopes to contain a thermonuclear reaction. During the last 20 years or so, several machines have been built to study the mechanism of fusion and to try to maintain the very high temperatures needed to cause fusion to occur continuously. None of these machines was successful. Then the Russians designed and built a machine called a *Tokamak*. Tokamaks operate in the following way:



Tokamak fusion generators.

The heart of a Tokamak consists of a doughnut-shaped chamber. The interior of this chamber is filled with a gas and minute amounts of deuterium. Heavy electro-magnets are clustered all around the doughnut. When all is ready, the gas inside the doughnut has an extremely heavy electric current pulsed through it, whereupon it heats up to a very high temperature and changes into a plasma.

As long as the current is kept passing through the plasma it will generate its own powerful magnetic field. This field, in conjunction with those that are produced by the magnets clustered on the outside of the machine, keeps the intensely hot plasma away from the sides of the doughnut. One touch of this filmy plasma would immediately vaporise the metal walls of the chamber! The heat generated by this plasma should, under ideal conditions, set off a deuterium fusion reaction which becomes self-sustaining! Each fusion releases less energy than that attained from uranium fission, but since one gram of deuterium contains about 100 times as many atoms, the total amount of energy released by a fusion reaction involving one gram of deuterium is approximately three times as great as that given out by a gram of fissioning uranium! Once scientists have managed to operate a fusion reactor successfully, without problems, its vast amount of generated heat can be used to change water into steam and thence to drive electric turbines and other machinery.

At the present time, several other nations are involved in their own Tokamak experiments but so far nobody has been able to maintain a high enough temperature, nor have they managed to contain the plasma properly in its central position within the doughnut. Several Tokamaks have had the same containment problem—the plasma touching the sides of the chamber and damaging the machine! Despite these setbacks, scientists and engineers still believe that a fusion reactor will be working before the end of this century and that these machines will produce all the heat energy man is ever likely to need for thousands of years!

INDEX

HOW AND WHY

These books answer the questions most often asked about science, nature and history. They are presented in a clear, readable style, and contain many colourful and instructive illustrations. Readers will want to explore each of these fascinating subjects and collect these volumes as an authentic, ready-reference, basic library.

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